



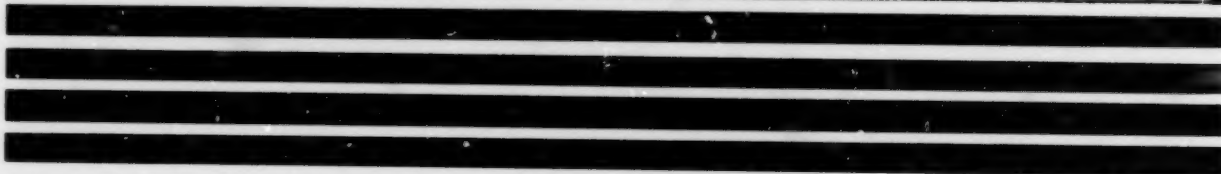
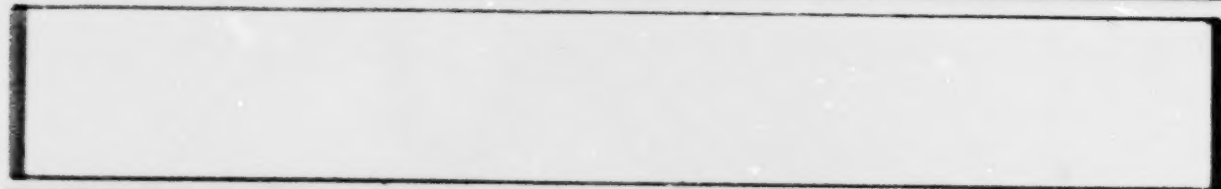
Saskatchewan
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SASK 21



Canada - Saskatchewan Renewables — Conservation Demonstration Program

Final Report





CANADA-SASKATCHEWAN CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

On March 18, 1980, the governments of Canada and Saskatchewan entered into a Conservation and Renewable Energy Demonstration Agreement. The Agreement, which terminates March 31, 1984, funds the development and demonstration of a wide range of conservation and renewable energy technologies. The program is funded on an equal cost-shared basis by Canada and Saskatchewan, and is administered by Saskatchewan.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies which exploit renewable energy resources, conserve energy, or make its use more efficient;
- To create employment in new or existing industries;
- To develop broad public awareness of the potential of renewable energy and energy conservation technologies.

This report outlines the results of a project funded by the Government of Saskatchewan as represented by Saskatchewan Energy and Mines, and the Government of Canada as represented by Energy, Mines and Resources Canada, under the terms of the Renewables-Conservation Demonstration Program, and contracted with the party identified herein.

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Energy-Efficient Radial Tined Discs

CONFIDENTIAL

Final Technical Report
on a Renewables-Conservation Demonstration Program Project

Conducted By

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And Supported By

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and
Energy Mines and Resources Canada

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Miscellaneous
Report FP-2

* TABLE OF CONTENTS *

	PAGE
INTRODUCTION.....	1
HYPOTHESIS.....	2
DEMONSTRATION.....	3
RESULTS.....	6
CONCLUSIONS.....	9
FIGURES.....	10
PHOTOS.....	13
TABLE.....	15
GRAPHS.....	16
STRIP CHART RECORDS.....	17
<u>APPENDIX A - DESIGN OF TINED DISCS</u>	23
- LEGEND.....	30
- FIGURES.....	31
- THEORITICAL ANANYSIS OF PERFORMANCE OF TINES.....	39
<u>APPENDIX B - COMPARER ROLLING FRAME</u>	42
- INSTRUMENTATION.....	44
- DATE ANALYSIS.....	46
- COMPARER ROLLING FRAME FIELD TESTS.....	48

INTRODUCTION

The radial tined discs project was conducted to evaluate the energy advantages of a new type of disc implement. The new type of disc implement which was tested can be used for soil tillage and is different from conventional discs in that it has tines mounted radially about the circumference of the disc. It was thought that the action of the tines in the soil would provide a reduction in implement draft compared to a standard type disc. A reduction in implement draft would in turn reduce the energy requirements of the field tillage operation.

Disc implements have always played an important role in prairie tillage and have recently enjoyed an increased popularity while other tillage implements have showed a decline in sales. (AGRICULTURAL ENGINEERING, Vol 62, No 7, p 21). There has been much work done to improve the efficiency and performance of the basic disc. Some work has been done with conical shaped discs as opposed to spherical discs. Borg Warner Corporation has introduced two new types of notched and relieved discs claiming greater energy efficiency (see Figure 1) (US patent 4,098,349 and 4,099,576).

There has also been a lot of work done on tined tillage equipment to improve energy efficiency. There are a large number of different types of tined tillage equipment. Some types rotate due to the manner in which they react with the soil while others are rotated by some power source while the implement moves longitudinally through the soil. Figure 2 illustrates a tined mulcher. Figure 3 illustrates a tined tillage tool with curved tines acting on the soil in a manner similar to a disc tiller. Figures 4 and 5 illustrate two other types of rotary tined tools. Russian reports claim an energy saving with their tests on the machine illustrated by Figure 4 (NAL translation NTML-WRG-851). Work done in England on yet another power driven tined implement shows improved energy efficiency (see Figure 6).

The present project combines both the disc and tined implements by placing short tines radially about a conventional disc in an attempt to combine the advantages of the tined implement and the disc. The old Morgan spading harrow would come close to acting like the radial tined disc (See Figure 7).

It was anticipated that the radial tined disc would be used for both primary and secondary tillage. The various potential advantages of this type of disc, including the potential for increased energy efficiency, made it attractive to attempt to develop this type of disc.

HYPOTHESIS

The load on a disc type tillage tool is caused by the soil reacting with the disc. This includes loads caused by the disc shearing and fracturing the soil, raising the soil and displacing the soil to one side at a considerable velocity. Some energy is also lost due to mechanical friction of the disc tool, friction between the soil and disc, and internal friction in the soil caused by soil pieces being caused to compress and slide over one another.

A tined disc encounters the same type of loads as a conventional disc but it was expected that the loads encountered by the tined disc would not be as large as the loads encountered by the conventional disc.

It can be seen that the disc portion of the tined disc which contacts the soil would have similar loads to a conventional or standard disc working at the same depth. However, under normal operating conditions the disc portion of the tined disc would be cutting only the surface of the soil whereas the disc portion of the conventional disc would be cutting the soil to a greater depth. In addition, the soil that the disc portion of the tined disc cuts is prefactured by the tines of the disc. Since the surface soil is usually looser than deeper soil, and since it is prefactured, the disc of the tined disc implement encounters very low shear loads. Since the disc portion of the tined disc only cuts the surface of soil that has already been loosened, the

disc portion of the tined disc should encounter loads that are much lower than the loads encountered by a conventional disc.

The tines of the tined disc were expected to create most of the load because they work the deeper, harder soil. However, the load contribution by the tines was expected to be less than a disc operating at the same depth because the disc must shear, raise, and displace all the soil it encounters. Since the tines are relatively narrow, they can pass easily through the soil in order to fracture the soil but, because much of the soil would pass between the tines, the tined disc was expected to raise and displace a smaller amount of soil than the conventional disc. The theoretical analysis of the action of the tines is outlined in Appendix A.

It was also expected that, because the tined disc would not displace and invert as much soil as a conventional disc, the tined disc would tend to leave plant residue laying on the surface or in the top layer of the soil, thus contributing to the conservation of moisture and the reduction of soil erosion.

DEMONSTRATION

Appendix A describes the process that was followed in the design of the radial tined disc implement.

A conventional disc gang and a tined disc gang were built to be compared during field trials. The two disc gangs were mounted on a specially constructed comparer rolling frame for the field trials. The principle of the comparer, its instrumentation and its operation during the field trials are described in Appendix B.

During the first series of field trials, the tined disc gang that was tested had 20 inch discs, with 4 inch tines and 9 inch spools. This gang worked satisfactorily in fallow soil but plugged fairly easily in stubble fields. To correct this problem, a modified type of tined disc was designed to clear

trash better. A larger, 24 inch disc was used with larger, 12 inch spools. The spaces between the tines was increased slightly from $7 \frac{3}{4}$ to $8 \frac{3}{4}$ inches. The tines were the same four inch tines used on the 20 inch disc. Scrapers were added to the gang. During a series of unmeasured field trials, this modified disc gang cleared trash much better than the previous model but it still plugged in very heavy trash conditions. However, the modified disc gang performed sufficiently well to allow measured field trials to be conducted.

In order to conduct measured field trials, a gang of five 24 inch tined discs was mounted on one side of the comparer folling frame and a gang of five 24 inch conventional discs was mounted on the other side of the comparer. Each of the tined discs had nine tines which were mounted on the discs in such a way that the tines followed the curvature of the surface of the disc. The tined discs gang was assembled in such a manner that the tines on adjacent discs were staggered. (See Photo 1). This staggered spacing of tines provided the optimal pattern of soil tillage and eliminated the tendency of the tined disc gang to bounce when the tines on each disc hit the soil at the same time. The reasons for staggering the spacing of tines on adjacent discs are discussed in more detail in Appendix A.

Since it was expected that the tined discs would leave a certain amount of deep soil unworked, because of the space between the tines, the gang of tined discs was adjusted to be 1.25 inches lower than the conventional discs to ensure that both the tined discs and conventional discs moved equal quantities of soil. Figure 8 illustrates the relative positions of the conventional and the tined disc gangs. When, as shown, the conventional discs penetrates a maximum of 4.75 inches the disc of the radial tined gang cuts the soil at only 2 inches, enough to cut vegetation. The tines penetrate another four inches maximum, another 1.25 inches beyond the conventional disc. The space between the tines was expected to make up for the extra depth of the tines. Figure

9 shows a typical cross section of the worked soil during a field trial. Photo 5 shows an area that has been tilled by the tined disc gang. The soil that has been loosened by the tined discs has been removed to show the unworked soil ridges left by the tines.

The conventional disc gang operated at a 25° angle to the direction of travel. However, in order to minimize the number of tines per disc, to facilitate trash clearance, and to ensure the discs had overlapping cuts, the tined disc gang was operated at a 45° angle to the direction of travel. Appendix A explains in more detail the basis for the need to operate the tined discs at a 45° angle. Both gangs of discs were composed of 5 discs and four spools. The width cut by the gangs was 2 feet 9 1/2 inches for the conventional gang and 2 feet 8 3/4 inches for the radial tined gang. The 12 inch spools of the radial tine gang gives the 45° gang a similar cut width to the 25° convention gang. The conventional gang being 3/4 inch wider than the tined sics is not significant as the lead disc of the radial tined gang would move more soil than the leading disc of the conventional gang. The 45° disc angle would expose the leading discs of the tined gang to make a wider cut compensating for the 3/4 inch difference. The practical purposes the cut width of both gangs are very close and can be compared.

A total of twenty seven measured field trials were conducted to compare the tined disc gang and the conventional disc gang. Trials were conducted in three different soil types at three different depths and at three different ground speeds. During the silt loam stubble trials, samples of loosened soil were collected from an area cultivated by the conventional discs and from an equal-sized area cultivated by the tined discs. The amount of loosened soil collected was then weighed. The method of collecting soil samples is shown in Photo 6. The results of these field trials are summarized on Table 1 and on graphs 1, 2, and 3. Twenty seven measure trials were conducted but twenty six were used on graphs. This is because valves for Trial 9

9 were too high and didn't show on the strip chart. An analysis of Trial 9 couldn't be made. The strip chart records of some of the field trials are attached to Appendix B. The strip chart records are all at 5 inches depth at 5.5 and 6.3 mph on three different types of soils.

RESULTS

Contrary of what was originally expected, the results of the measured field trials indicated that the draft of the radial tined disc gang was about 2.2 times greater than the draft of the conventional discs. Thus, instead of the expected energy saving, there is an energy penalty associated with the use of the radial tined discs for field tillage operations.

There appear to be four reasons why the tined discs have a higher draft than the conventional discs:

- the samples of loosened soil that were collected indicate that the tined discs loosened 15-20% more soil than the conventional discs. (See Table 1). It appears that the 4" tines should have been shortened by approximately 1/2 inch to ensure that equal quantities of soil were worked by the conventional disc gang and by the tined disc gang.
- as was previously indicated, as the depth of tillage increases, the amount of draft experienced increases rapidly. Since the tined discs were set to work soil 1.25 inches deeper than the conventional discs, the tined discs experienced more draft than the conventional discs. Since the extra soil that was loosened by the tined disc gang came from a significant depth, it is likely that the extra 15-20% of soil loosened by the tined discs resulted in an increase of 30-40% in draft. Graph 2 seems to indicate that at greater depths, the ratio of tined disc draft to conventional disc draft seems to increase.

- it was expected that the tines would pass easily through the soil, and that the loosened soil would pass between the tines without being raised or displaced. The model tests that were conducted also seemed to confirm that the tined disc would perform in this manner at low speeds. However, during the field trials it was discovered that, at normal field speeds such as 4, 5 or 6 miles per hours, the tined discs tended to rotate very rapidly. Because of this rapid rotating action, the tined disc tended to act like a garden roto-tiller, pulverizing the soil, mixing it and raising it to the top of the discs before releasing it. This mixing and pulverizing action requires a considerable amount of energy. By comparison, the conventional disc tends to produce large clods of soil which are not thoroughly mixed. Graph 3 seems to indicate that, at increased speeds, the ratio of tined disc draft to conventional disc draft seems to increase. Photos 3, 4 and 7 show the pulverized, mixed soil produced by the tined discs and the unmixed soil and the large clods produced by the conventional disc. Photo 8 shows how the soil is lifted and mixed by the tined discs.
- the tined disc was operated at a 45° angle to the direction of travel while the conventional disc was operated at a 25° angle. There has been considerable documentation in professional publications indicating that an increase disc angle increase draft (ASAE, Vol. 23, No. 2, 1980, p. 268 and CAE, Vol. 18, No. 1 1976, p 52).

During the field trials, the tined discs easily penetrated hard packed soils containing dense root structures (See Photo 2). In normal fallow situations, the tined discs tended to leave weeds uprooted on the surface of the soil (See Photo 4).

The weed kill in soils which had weeds with extensive root systems proved to be better with the radial tined disc. The conventional disc cut these soils into large clods as can be seen on the right hand portion of Photo 2. The root systems survived much better in the large clods of soil and recovered. The root systems found in the larger clods of the conventional disced soil would have an even greater chance of survival if it rained on the soil even several days after tillage.

The weed kill on stubble soils and on soils with a large weed population was also better with the radial tined discs. Again the obvious reason was because the soil was pulverized to a greater extent. This can be seen in Photos 3, 4 and 7. The larger chunks reacted by a conventional disc could support life in some plants long enough to survive, especially if part of the soil chunk was buried. The more finely pulverized soil of the radial tined disc destroyed root systems leaving the plants and roots to dry on the surface or in the loose soil.

If the radial tined disc was operated to shallow, only the tines would work the soil. This condition would result in plants between the tines being damaged but not killed. It is important to have the radial tined disc deep enough so that the disc would at least cut all the weeds at the surface. The tines would then work up the root system.

The great and unexpected amount of soil pulverizing is not the most desirable. The highly pulverized soil would be subject to easier soil erosion. The pulverized soil being less dense would also dry very easy. The moisture loss would be detrimental for the dryer regions of the prairies resulting in poor crops. The moisture loss would also contribute to the loss of nitrogen available to plants as the nitrogen is carried in the moisture. In areas of higher rainfall the concern of soil drying would not

be a great factor in crop yield as adequate supplies of moisture would be available. In much of the prairies crop yield is dependent on the soils ability to hold and reserve moisture.

The radial tined disc was operated for the recorded trials and for trials which were not recorded. The unrecorded trials were used to observe performance of the disc. There were at least twice as much unrecorded tillage as recorded tillage. Neither tined disc nor the conventional disc showed abnormal wear.

CONCLUSIONS

The tined disc appears to be less energy efficient than a conventional disc. However, the tined disc may be more energy efficient than a moldboard plow or a chisel plow. As well, the radial tined disc may be a more energy efficient tillage method than some other conventional cultivation practices. For example, because of its pulverizing, mixing action, one tillage operation by the radial tined disc may replace conventional cultivation practices involving several different tillage operations such as plowing or chisel plowing followed by harrowing or mulching.

If a decision is made to proceed with the commercial manufacturing of the tined disc, additional development work should first be done to improve its energy efficiency, to improve its trash clearing ability and to make it more economical to manufacture and to maintain.

Morris Rod Weeder will not be pursuing the development of this disc because of priorities forced on us by the current recession and because the disc didn't prove to be a light draft implement. Knowledge gained from demonstration can be useful in helping us with the manufacture and sales of our conventional disc. Future developments in tillage and machinery may receive interest in the radial tined disc.

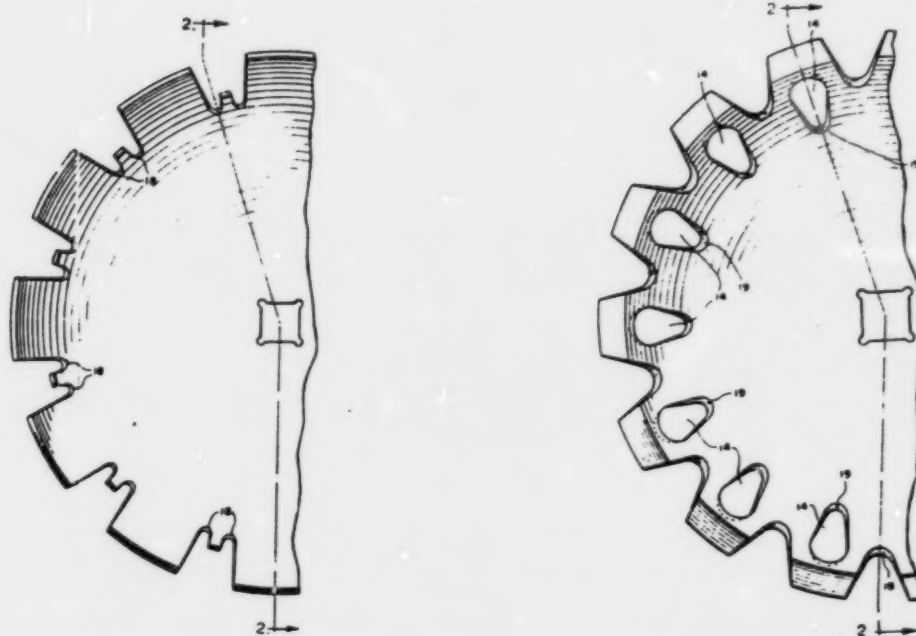


FIGURE 1 Borg Warner energy efficient discs

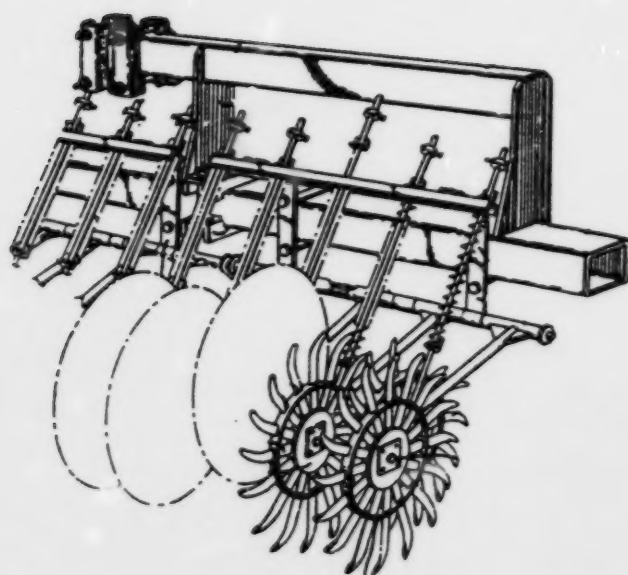


FIGURE 2 Tined Mulcher

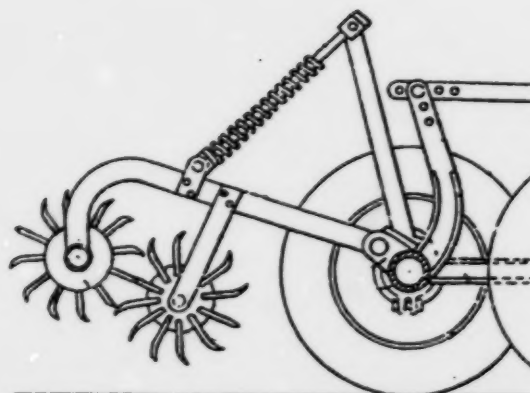


FIGURE 3 Disc Like Tined Tool

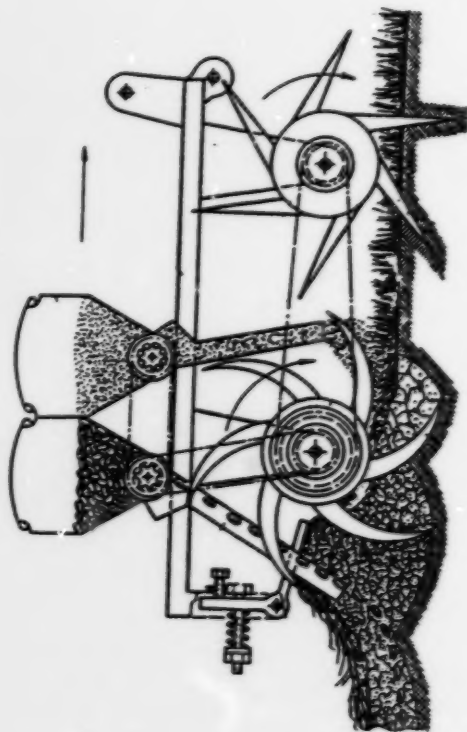


FIGURE 4 Russian Tined Tillage Tool

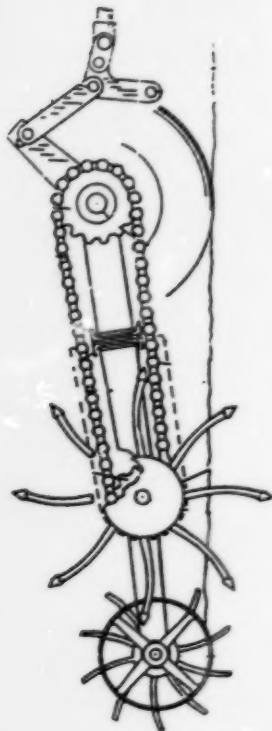


FIGURE 5 US Tined Tillage Tool

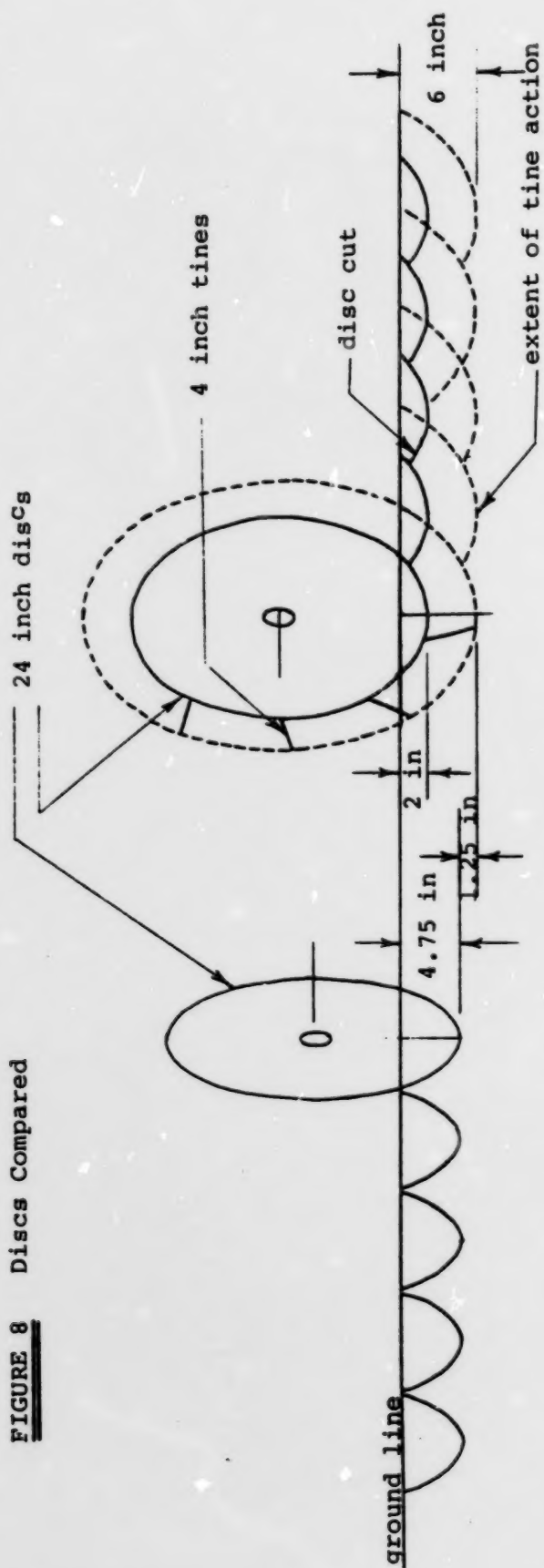


FIGURE 6 British Powered Tool



FIGURE 7 Early Disc Like Tined Implement

FIGURE 8 Discs Compared



-12-

Conventional Disc
25° Disc Angle

Tined Disc
45° Disc Angle

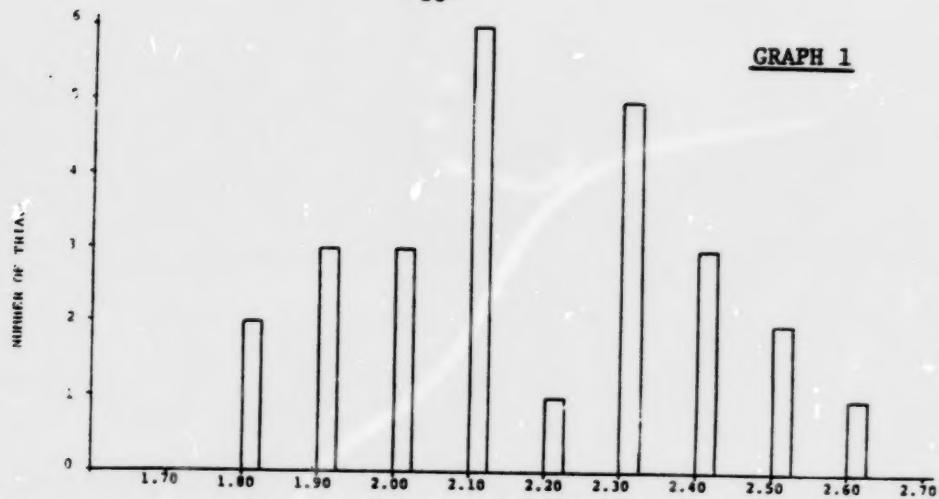
FIGURE 9 Soil Cross Section



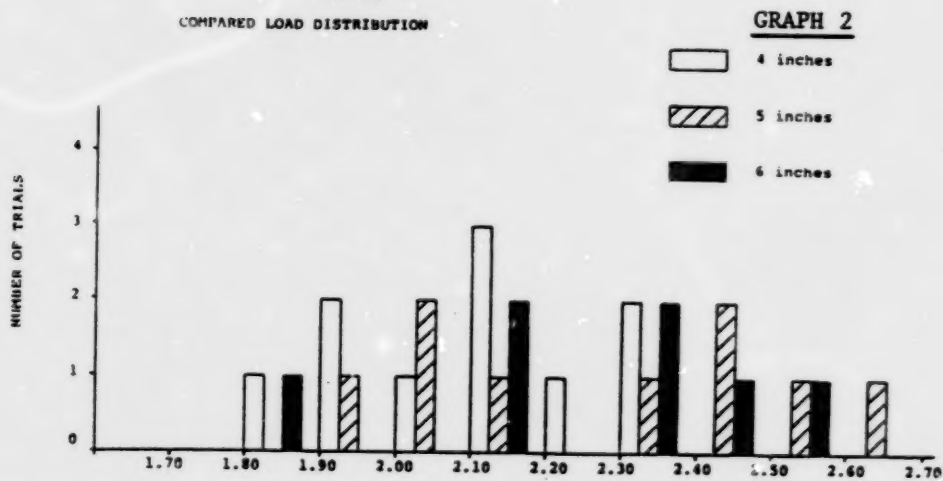
TABLE 1 TRIAL DATA COMPARED

TRIAL	SOIL	DEPTH INCHES	MPH	TINED DISC LOAD (LBS)	STD DISC LOAD (LBS)	COMPARED LOADS (TINED STD)	PERCENT MATERIAL TILLED (TINED STD) X 100	COMPARED LOADS ADJUSTED (TINED STD) X %
1	SILT LOAM STUBBLE	4	4.1	1320	670	1.97 h	122	1.61
2		4	5.5	1870	990	1.87 f	116	1.61
3		4	6.3	1770	867	2.04 f		
4		5	4.1	2420	1180	2.05 g	97	2.11
* 5		5	5.5	2280	927	2.46 g	137	1.71
* 6		5	6.3	2927	1250	2.34 f		
7		6	3.5	2420	1255	1.93 g		
8		6	4.1	2257	1200	1.88 g	121	1.48
9		6	5.5		1980		110	
10	SANDY FALLOW	4	4.1	682	294	2.32 h		
11		4	5.5	830	388	2.14 h		
12		4	6.3	969	446	2.17 g		
13		5	4.1	1425	581	2.45 h		
*14		5	5.5	1617	841	1.92 g		
*15		5	6.3	1884	871	2.16 h		
16		6	4.1	2279	979	2.33 g		
17		6	5.5	2538	1171	2.17 g		
18		6	6.3	2835	1235	2.30 g		
19	CLAY LOAM FALLOW	4	4.1	780	343	2.27 h		
20		4	5.5	1127	477	2.36 h		
21		4	6.3	1007	460	2.19 h		
22		5	4.1	2593	983	2.64 h		
*23		5	5.5	2213	1090	2.03 g		
*24		5	6.3	2937	1177	2.50 h		
25		6	4.1	3260	1493	2.18 g		
26		6	5.5	3370	1363	2.47 g		
27		6	6.3	3560	1407	2.53 g		

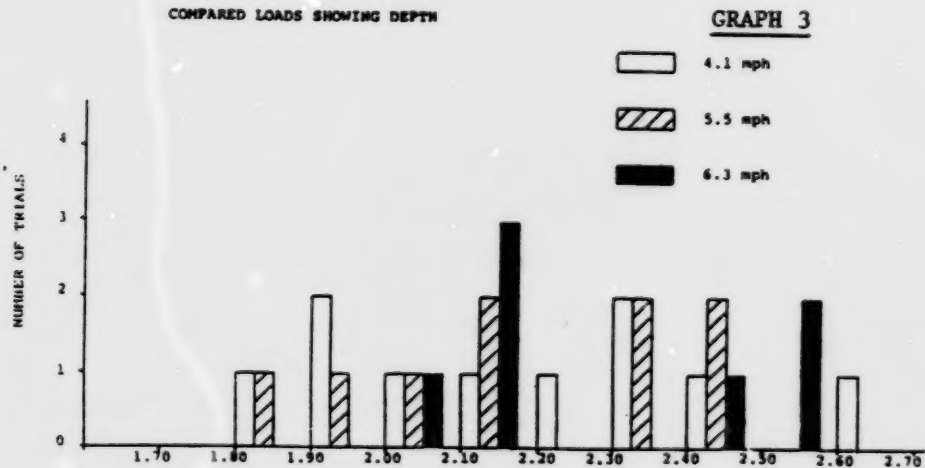
*illustrated trials
degree of parallelism h-high g-good f-fair l-low u-unacceptable



Timed lbs
Std lbs
COMPARED LOAD DISTRIBUTION

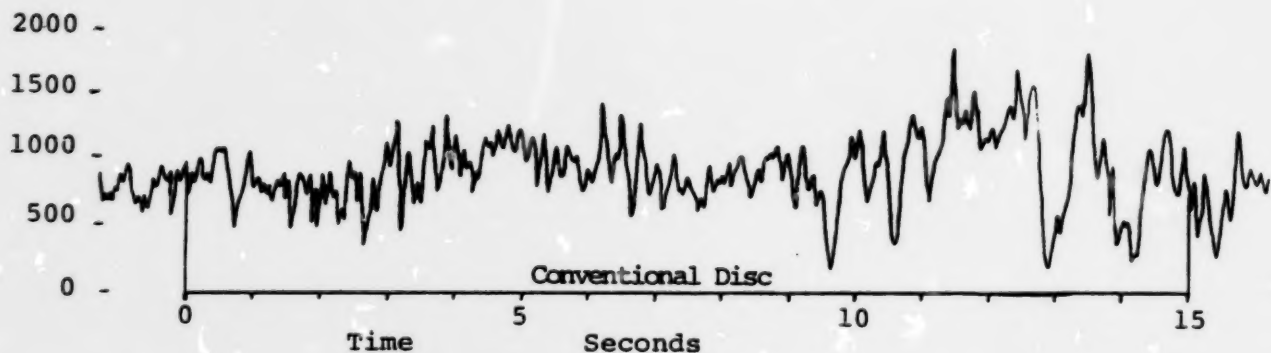
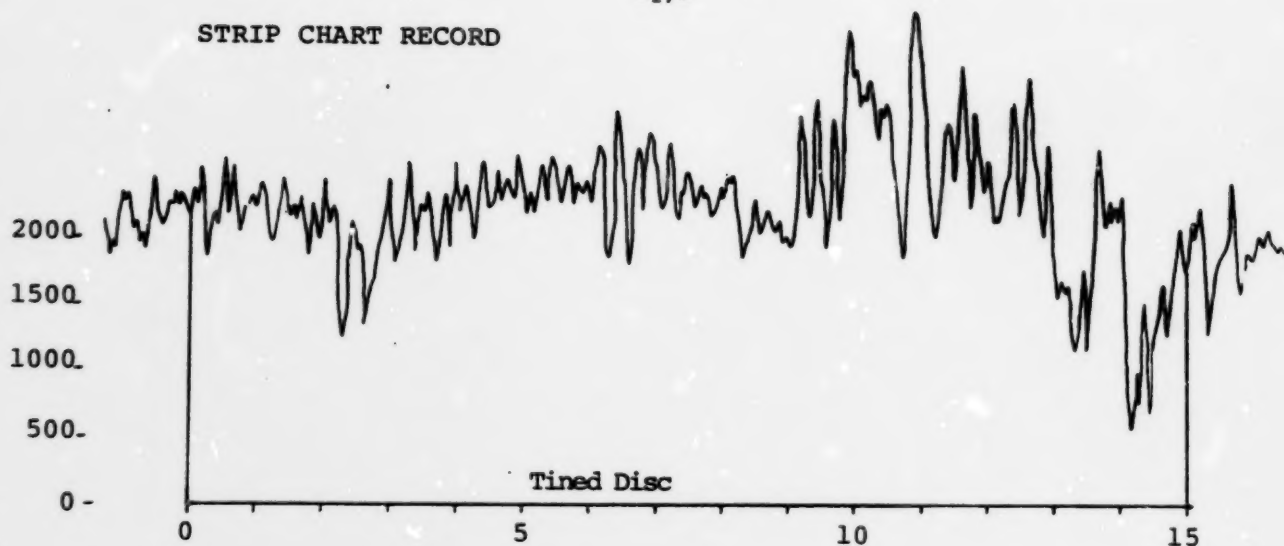


Timed lbs
Std lbs
COMPARED LOADS SHOWING DEPTH



Timed lbs
Std lbs
COMPARED LOADS SHOWING SPEED

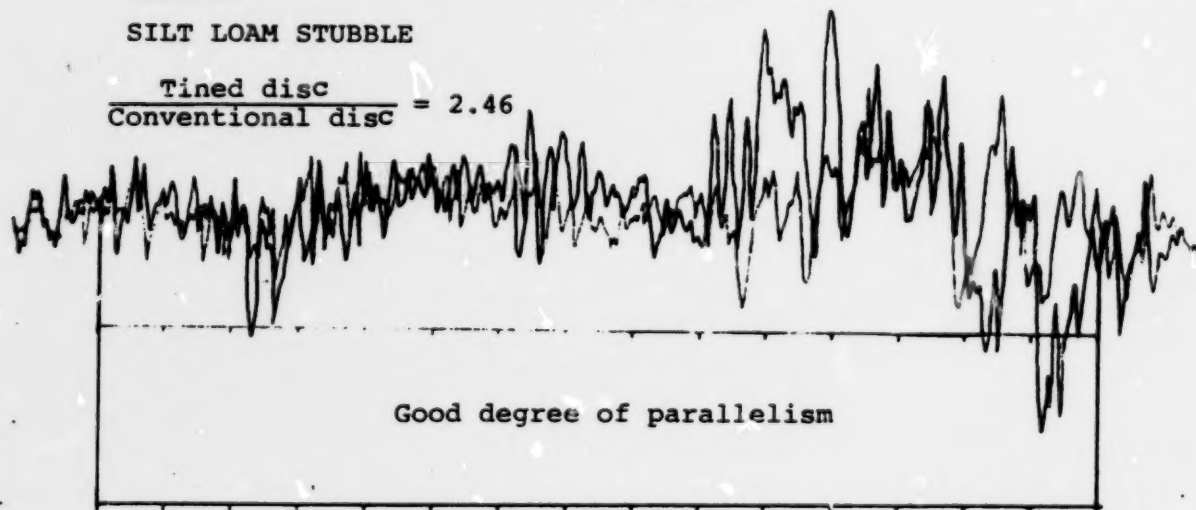
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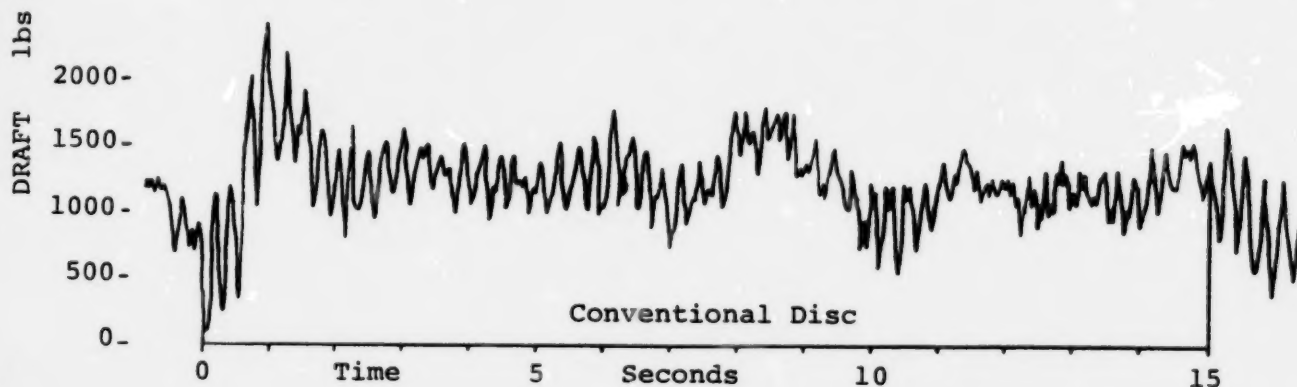
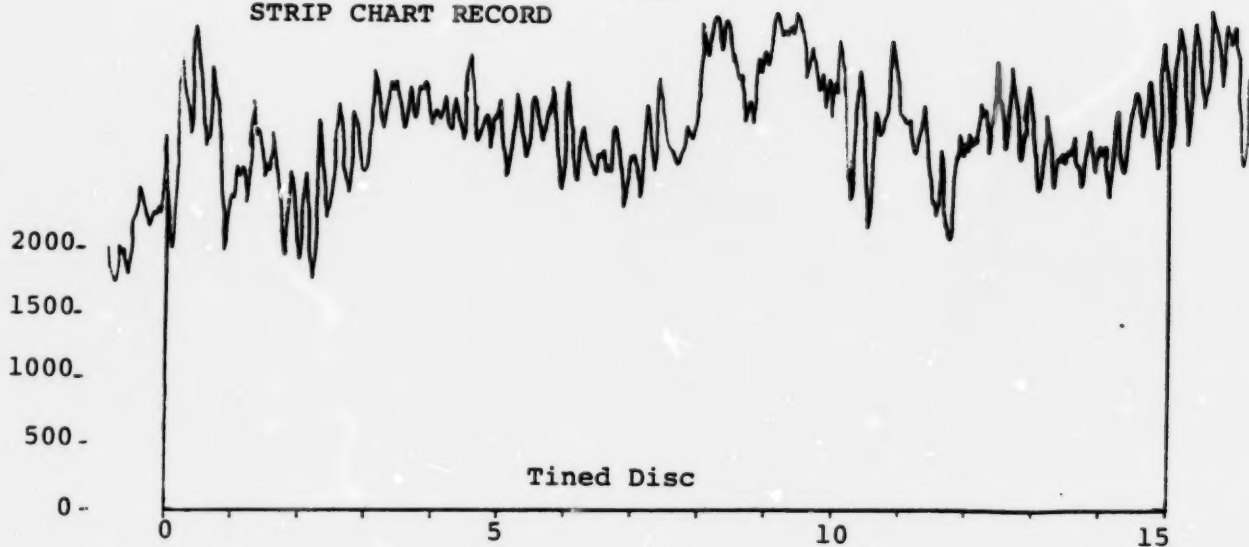
TRIAL 5 depth 5 in speed 5.5 mph

SILT LOAM STUBBLE

$$\frac{\text{Tined disc}}{\text{Conventional disc}} = 2.46$$

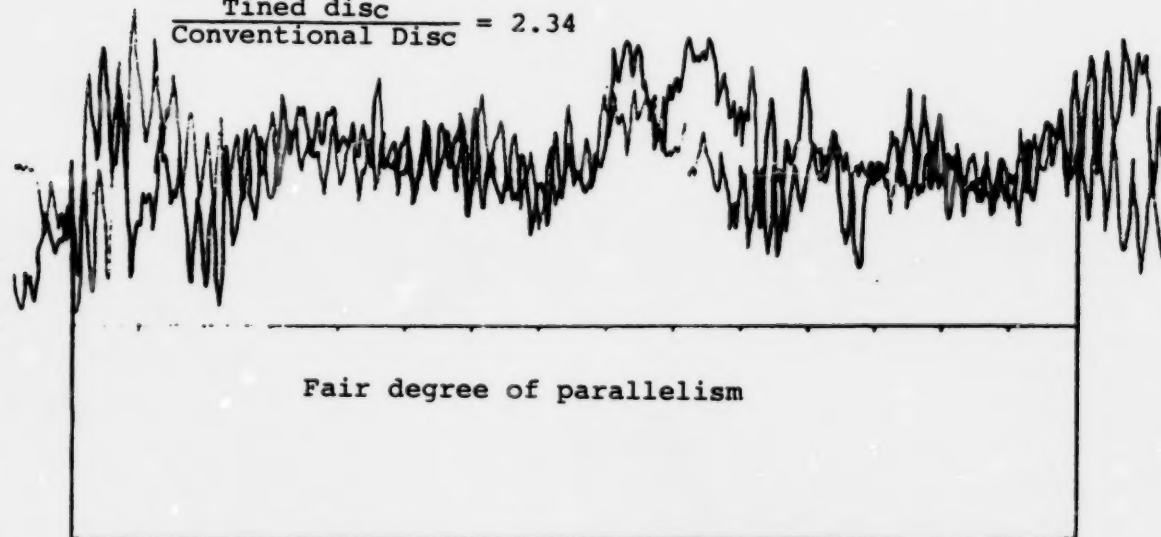


STRIP CHART RECORD

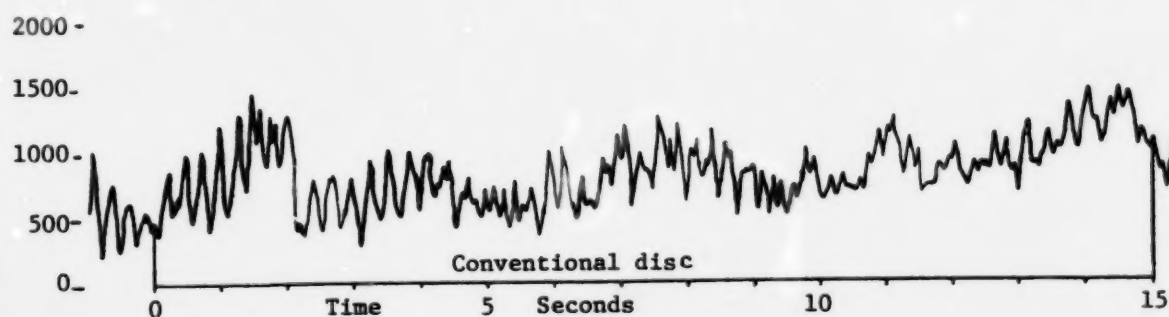
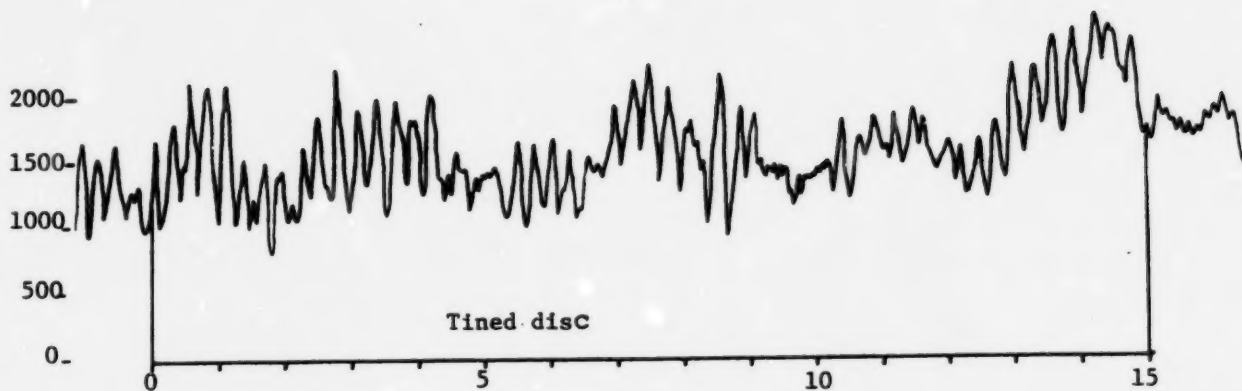


TRIAL 6 depth 5 in speed 6.3 mph
SILT LOAM STUBBLE

$$\frac{\text{Tined disc}}{\text{Conventional Disc}} = 2.34$$



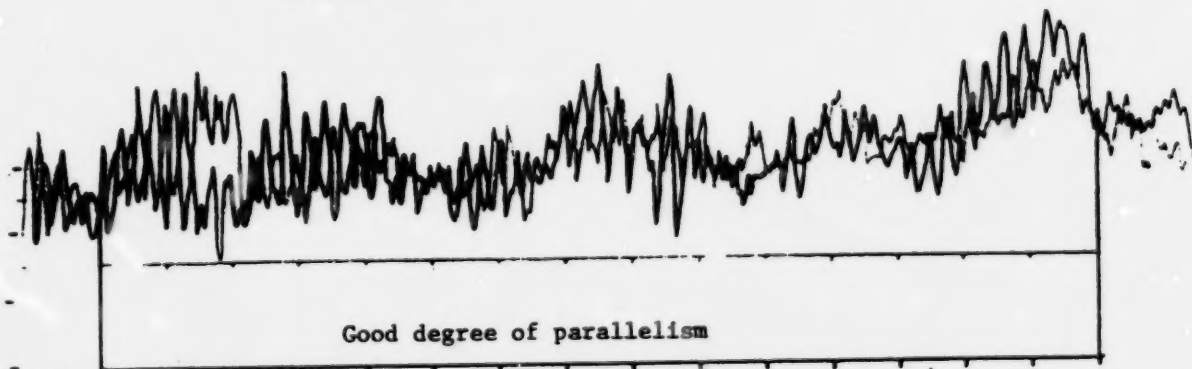
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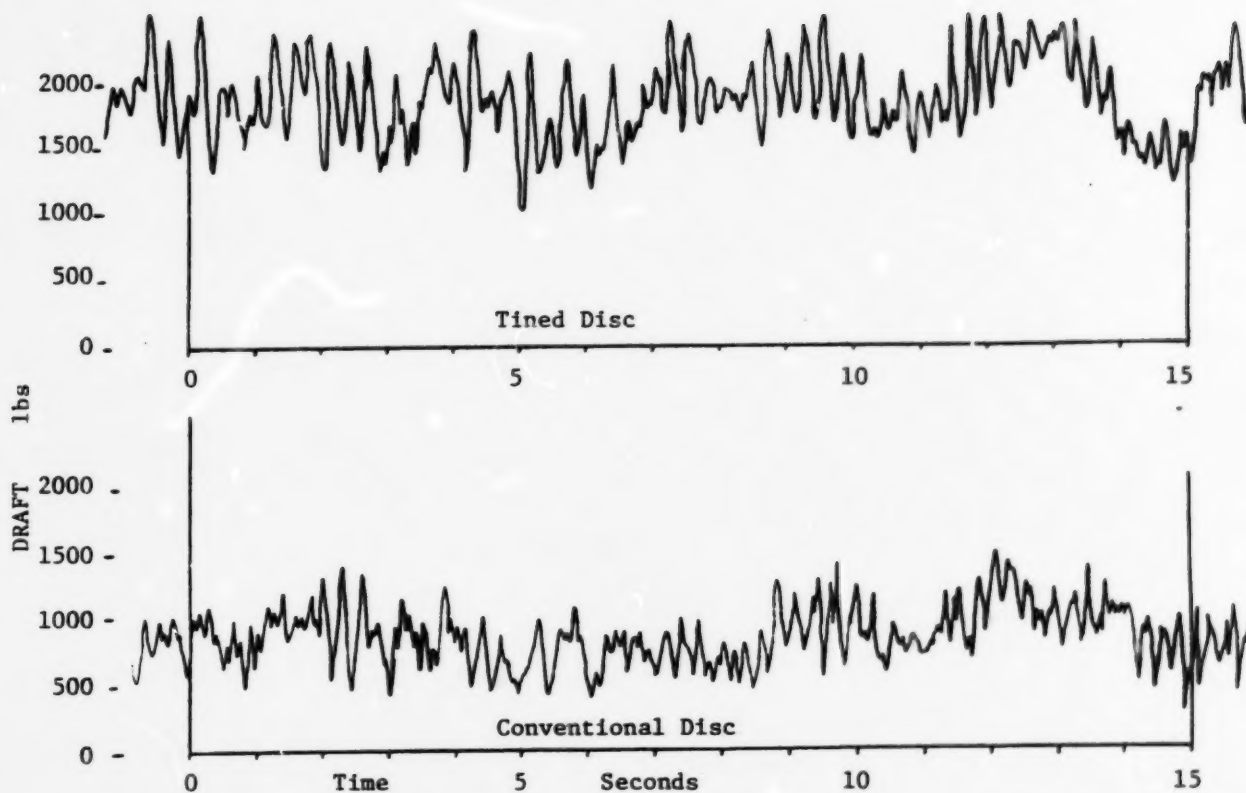
TRIAL 14 depth 5 in speed 5.5 mph

SANDY FALLOW

$$\frac{\text{Tined disc}}{\text{Conventional Disc}} = 1.92$$



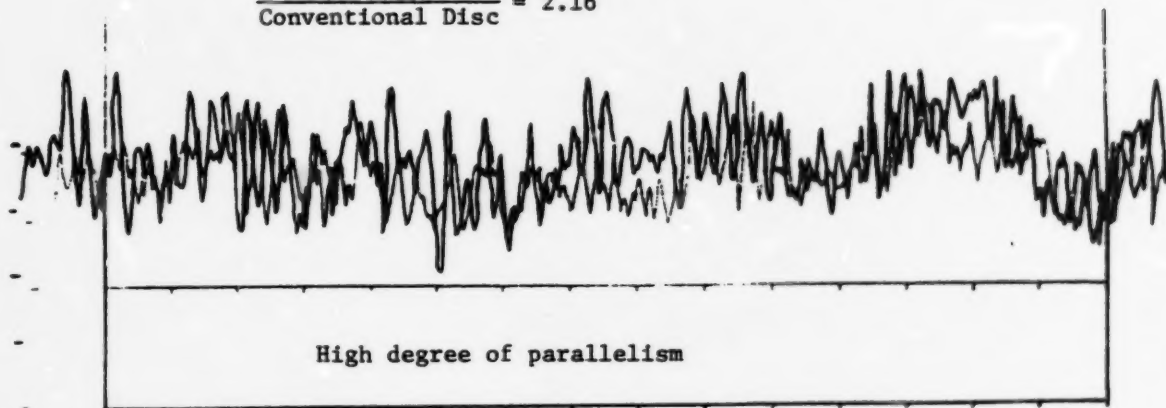
STRIP CHART RECORD



TRIAL 15 depth 5 in speed 6.3 mph

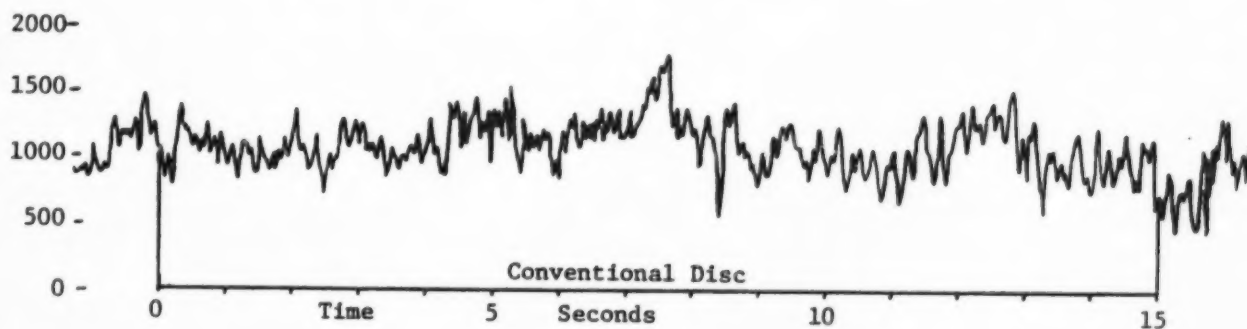
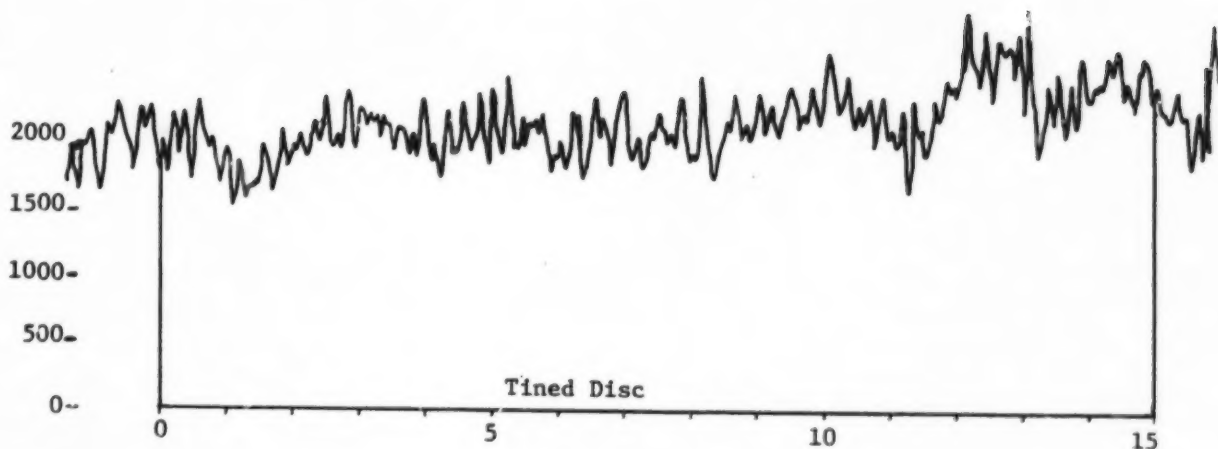
SANDY FALLOW

$$\frac{\text{Tined Disc}}{\text{Conventional Disc}} = 2.16$$



STRIP CHART RECORD

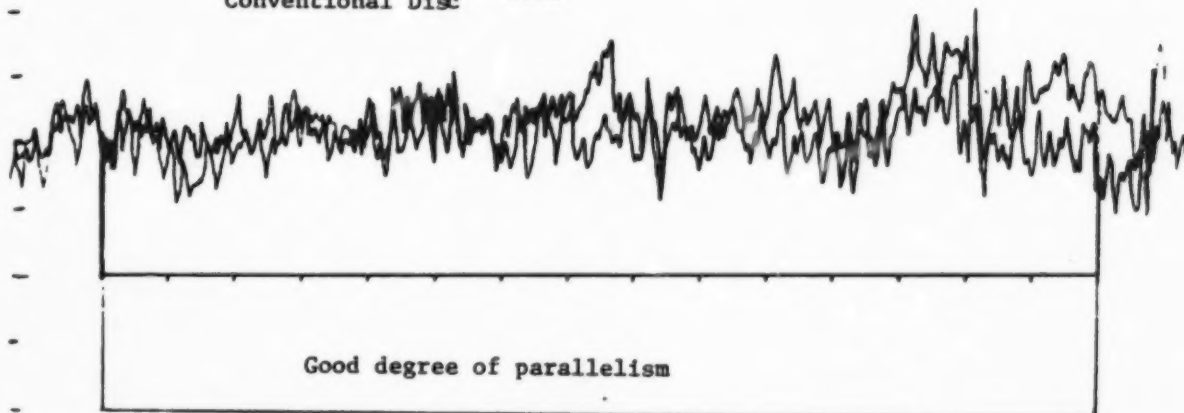
-21-



TRIAL 23 depth 5 in speed 5.5

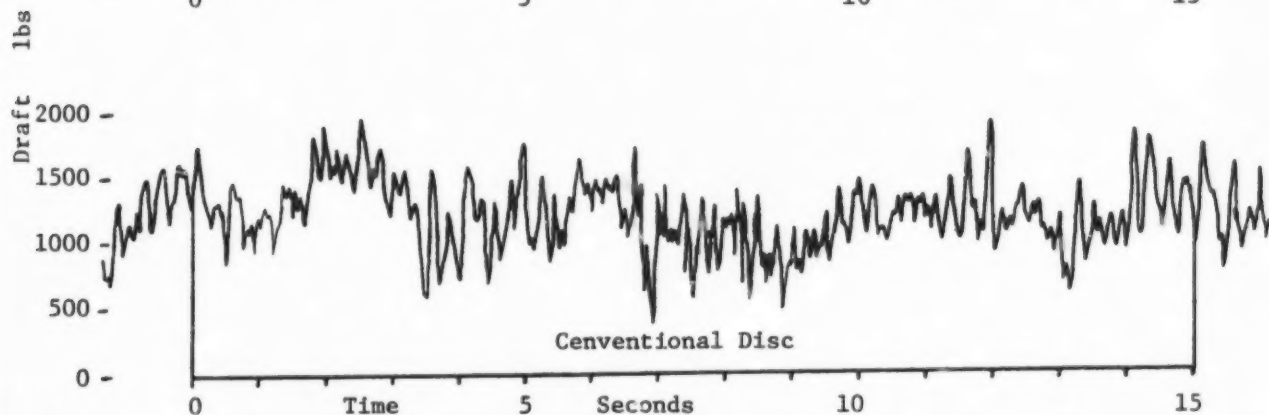
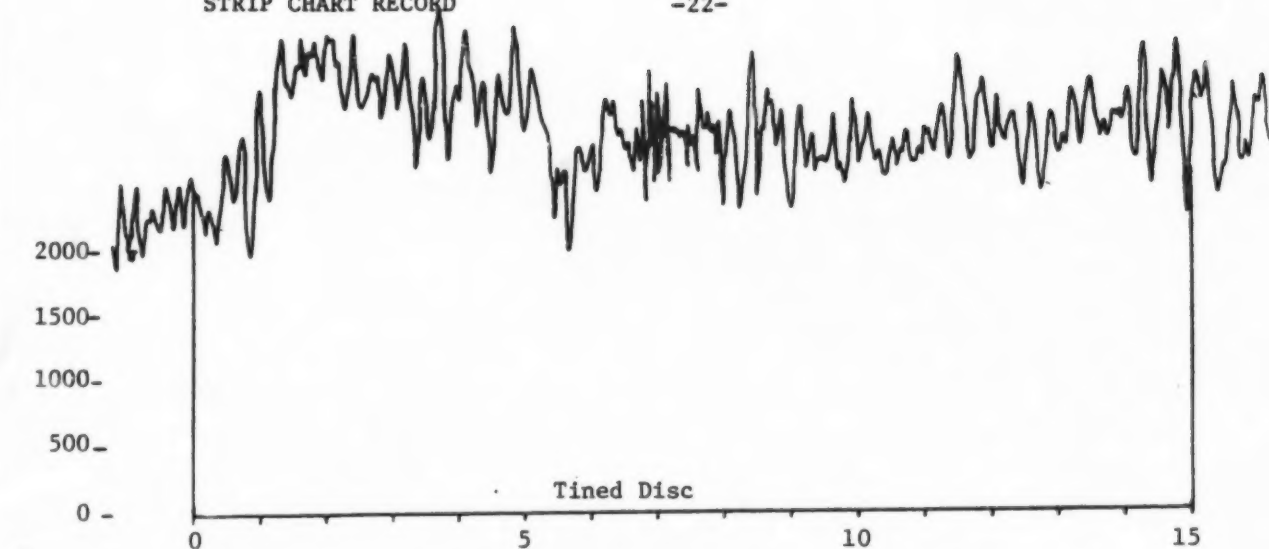
CLAY LOAM FALLOW

$$\frac{\text{Tined Disc}}{\text{Conventional Disc}} = 2.03$$



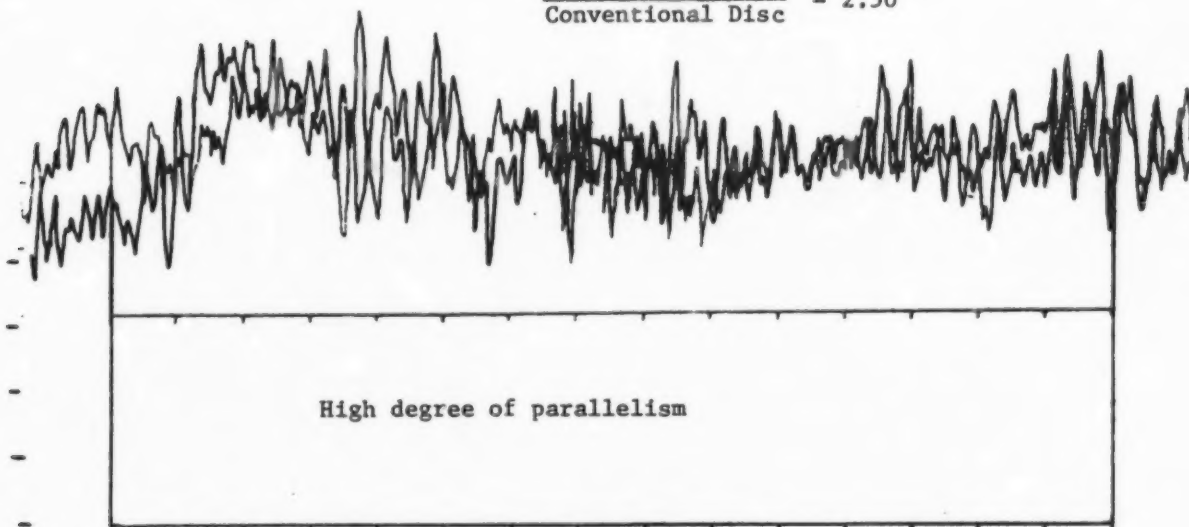
STRIP CHART RECORD

-22-



TRIAL 24 depth 5 in speed 6.3 mph
CLAY LOAM FALLOW

$$\frac{\text{Tined Disc}}{\text{Conventional Disc}} = 2.50$$



APPENDIX A - DESIGN OF TINED DISCS

General

It was decided that in order to minimize manufacturing and maintenance costs and to facilitate trash clearance, the number of tines should be minimized. The best way of minimizing the number of tines was to minimize the number of discs. (This also facilitated trash clearance.) In order to minimize the number of discs, the discs would have to be operated at a large angle from the direction of travel of the implement. This large disc angle would maximize the amount of space that could be worked by each disc so the number of discs required to work a particular width could be minimized. It was felt that it would not be practical to exceed a disc angle of 45° .

It was recognized that, the larger the disc angle, the greater the draft would be per unit width (Harrison 1977). However, this fact was considered to be of less significance in the case of the tined disc because the disc portion of the tined disc implement only penetrates the soil to a depth of 2 inches. As well, the tines of the disc would fracture and loosen the soil before the disc would contact the soil. Since the disc would only encounter a small amount of loose, dry, surface soil, the greater draft requirements of discs with large disc angles was not considered to be a major problem.

Construction of Test Model

The simplest possible configuration of the tined disc implement was constructed as a test model to obtain data to aid in further design of the discs and to provide information about previously unknown advantages and disadvantages of the discs. The test model also provided confirmation of the theoretical kinematic action of the discs and tines.

The test model consisted of a gang of four discs. Each disc had six tines. The test model was constructed in such a way that adjustments could be made to such features as weight distribution, disc spacing, disc angle, tine size and configuration, and hitch point.

The test model was constructed using a high ratio of disc spacing to disc diameter - 1 to 2 - to minimize the number of discs and tines. Tests were conducted with the test model set at various disc angles. The tests of the model set at the 45 degree disc angle and the 30 degree disc angle were recorded and developed further.

Tests indicated that, because of the high ratio of disc spacing to disc diameter, in order to work the entire surface of the soil at a 30 degree disc angle, it would be necessary to work portions of the soil to a significant depth. However, if the disc angle would be increased to 45⁰, then it would only be necessary to work the soil to a maximum depth of 4 cm (2 inches) in order to work the entire surface of the soil. If the disc is operated at a depth of 5 cm to cut weeds, a tine which extends radially from the disc axis and from the edge of the disc by a distance of 10 cm, (4 inches) would be adequate to ensure proper cultivation since most tillage operations do not exceed 15 cm (6 inches) in depth.

These test results are consistent with other information sources. This information was demonstrated by Thompson and Kemp graphically (1958) and also in the soil patterns that were developed for both 45 and 30 degree disc angles (See Figures 1A and 3A).

Theoretical Analysis of Performance of Tined Discs

Although many of the disc parameters of conventional discs are similar to the disc parameters that apply to tined discs, all of the disc parameters are not identical because of the presence of the tines on the tined discs. The parameters of conventional discs needed to be reassessed to see if they applied to tined discs.

The theoretical kinematic action of the tined discs was graphed and drawings were made of the soil patterns that would be produced by the discs.

The first test model mentioned which was made with a multitude of adjustments, served to confirm and test some of the theoretical ideas about the radial tined discs. The model gang was purposely made small so that it could be handled easily. It had six tines on each of its four smaller discs.

The analyse of the pneumatic action of the disc was done for a radial tine disc that was of a size that could have been used in actual field conditions. The analyse shows a disc 20 inches in diameter with eight evenly spaced tines which are four inches long. Larger or smaller discs could have been shown with more or fewer tines. The soil pattern would have been the same except the tine and disc paths would have been closer together or further apart. The use of various disc angles or aligned or staggered tines is independent of disc size or the number of tines. The soil patterns shown in Figure 1A - 8A are representative of any size of disc for the specific condition. Due to trash clearing problems we required a larger 24 inch disc with nine tines slightly further apart and with larger spools. The theoretical analysis for the 24 inch disc with nine tines would be the same as for the 20 inch disc with eight tines, as it would be for any size disc with any number of tines. The only difference would be a difference of scale, that is the patterns would be larger or smaller. The following discussion on the action of the tined disc would be representative for all tined discs of this type.

It was observed that the tines consistently move in the soil in a direction F that is about 45 degrees from the direction of travel E. This angle becomes somewhat smaller when the disc angle V becomes greater. For example with a disc angle of 45 degrees the tines move at about 40 degrees. (Note the angle of F in soil patterns)

$$\text{The disc parameter } \lambda = \frac{V_c \text{ rotational velocity}}{V_f \text{ velocity forward}}$$

(Hendrick and Gill 1971) appears to be larger for tined discs run at a disc angle of 30 degrees than for the tines disc run at a disc angle of 45 degrees. This can be explained by first viewing the tine as a single shank mounted on the disc axis with bearings. Upon forward movement the shank will seek the path of least resistance. Being constrained by the disc axis the shank will be displaced to the side. Being constrained by other shanks mounted concurrently and in fixed positions on the disc axis and being constrained to a minor extent by the disc the shank will move forward and to the side forming a path of approximately 45 degrees in relation to direction of travel.

With a disc angle of 30 degrees if the discs moved a peripheral distance of S the forward distance would be approximately

$$p = \frac{S \sin P}{\sin s}$$

(Figure 6A)

$$p = 250 \frac{\sin 105^\circ}{\sin 45^\circ} \quad s = 250 \text{ cm (10 in)} = \text{distance from point to point on tines of the model}$$

$$p = 341.5 \text{ cm (13.6 in)}$$

With a disc angle of 45 degrees if the disc moved a peripheral distance of s the forward distance would be approximately

$$p = s \frac{\sin P}{\sin S}$$

$$p = 250 \frac{\sin 95}{\sin 40}$$

$$= 387.5 \text{ cm (15.5 in)}$$

It can be seen that λ for a tined disc should be greater for the machine with the 30 degree disc angle since:

$$\lambda = \frac{V_c}{V_f} = \frac{S}{P} = \frac{1}{\frac{\sin P}{\sin S}} = \frac{\sin 45}{\sin 105} = .732$$

where as λ for a 45 degree disc angle would be:

$$\lambda = \frac{V_c}{V_f} = \frac{S}{P} = \frac{\sin S}{\sin P} = \frac{\sin 40}{\sin 95} = .645$$

It can be seen that theoretically the discs must rotate at higher velocities with a 30 degree disc angle than the 45 degree disc angle. The co-efficient of disc rotation worked on by Butsolich 1964, $\delta = \frac{N_a}{N_c}$ actual number of rotations / calculated number of rotations would play a small role on both δ or λ since the frictions and slippage on conventional discs would not exist to a large extent with radial tined discs because the tine secured the disc against slippage. It can be assumed that the parameter should have approximately a $\frac{\sin S}{\sin P}$ relationship.

$$\lambda = \frac{V_c}{V_f} = \frac{S}{P} = \frac{\sin S}{\sin P}$$

This theoretical relationship roughly describes the action and spacing furrows G.

Field measurements come close to confirming the theoretical results. The distance from point to point on the tines is 10 inches (250 cm). With the 45 degree disc angle p measured approximately 16 inches. The theoretical value was 15.5 inches. With the 30 degree disc angle p measured 11 inches. The theoretical value was 13.6 inches. This difference in value could be explained by realizing that the real value of S is probably less than 10 inches at a point partway up the tines. This case is similar to the fact that the rolling diameter of a sheeps foot packer is equal to a distance partway up the packer feet and is not equal to the packer diameter measured at the end of the feet. Value differences can also be attributed to slip and friction or $\delta \frac{Na}{Nc}$ of the rotating disc.

The arrangement of the tines could be made so that all tines are in line with the disc axis or so that every other disc is staggered so that the tines are spaced between the aligned tines. With the alternating arrangement with the 30 degree disc angle there is little functional difference in soil pattern, (Figure 1A and 2A). It may however help to clear plant residue from the tines.

With a 45 degree disc angle there is a marked difference in the soil pattern. With the tines in line, (Figure 3A), the furrows cut by the tines are at a 45 degree angle to the direction of travel. In this case the tines overlap worked area by 1.5 times as noted by worked areas X, Y, and Z, in Figure 3. By staggering the tines, (Figure 4A), every second tined furrow is moved half the distance P into the space unfurrowed by tines. This distributes the tined furrows uniformly over the disced area making the configuration of a 45 degree disc angle with staggering tines the best. The other feature which makes this configuration ideal is that at shallow depth - 2 inch as on a 20 inch discs - there is overlap on disc cut R, (Figure 4A), thus providing total weed cut, whereas with the 30 degree disc angle there are uncut strips R left by the discs, (Figure 1A).

Another problem with the discs with in-line tines is that the discs bounce up when all the tines hit the soil at one time. This bounce is quite severe. It is eliminated when alternate discs have their tines between the tines on other discs.

The tine furrows G developed by the 30 degree gang are shorter than that developed by the 45 degree gang. The tine furrows developed by 30 degree gangs are closer together per discs than those developed by 45 degree gang. The shortest distance between furrows is T which is equal to $S \cos U$. U is the difference between the disc angle V and the angle of the furrow, (Figure 6A).

$$T = X \cos U$$

30 degrees disc angle

$$T = S \cos 15$$

$$T = .966 S$$

45 degree disc angle

$$T = S \cos 5 = .996 S$$

Though the distance between the furrows of the 45 degree gang are spaced slightly further apart, the staggered tined version puts every alternate furrow half way between distance T. This makes a furrow pattern that is quite thorough, (Figures 4A and 5A).

The tines extending from the disc make an imaginary disc which extends the real disc A or K by the length of the tines. The edge of this imaginary disc is Q or B. The cut that this imaginary disc would make is N. The length of the furrow would then be:

$$G = \frac{N}{\cos F}$$

With a 30 degree disc angle the disc cut is N.
With a 45 degree disc angle the disc cut would Be:

$$N = \frac{\cos 45 \text{ degree } N}{\cos 60 \text{ degree } N} = 1.414 \text{ times larger than the discs}$$

cut with the 30 degree disc angle. This is confirmed by practice and graphically.

In fact with a 50 cm, (20 inch) disc at a 30 degree disc angle and a depth of 5 cm, (2 inch) (M) and a 25 cm, (10 inch) disc spacing there is uncut portion R between the discs of about 6 cm, (2.5 inch). This is shown graphically in Figure 1A. With the same conditions except a 45 degree disc angle there is an overlap of disc cut R by about 2.5 cm, (1 inch). This is shown graphically on Figures 3A and 4A.

With a 45 degree disc angle the furrow length is much longer. Thus tines on the discs can be staggered to get thorough furrowing of the soil because the long furrows with in-line tines overlap each other by about 1.5 times. This is noted in Figure 3A, X, Y and Z. Since N is 1.414 times larger with a 45 degree disc angle the furrows will be much longer.

$$G (\text{furrow length}) = \frac{N}{\cos \text{ of furrow angle}}$$

$$30 \text{ degree disc angle } G = \frac{N}{\cos 45} = 1.414 N$$

$$45 \text{ degree disc angle } G = \frac{1.414 N}{\cos 55} = 2.465 N$$

With a degree disc angle the furrow would be $\frac{2.465 N}{1.414 N} = 1.743$ times larger than with a 30 degree disc angle. This theoretical result is confirmed by field trails.

LEGEND

- A - disc circumference
- B - circumference formed by tines
- C - tines
- D - staggered tines on alternate discs
- E - direction of travel
- F - furrow angle or furrow path formed by the tine, with a 45° disc angle F = approximately 55° with a 30° disc angle F = approximately 45°
- G - furrow or furrow length
- H - furrow width probable extent of soil fracture
- I - edge of disc cut
- J - edge of disc cut
- K - top view of disc
- L - disc axis
- M - soil level 5 cm (2 inch) on disc 15 cm (6 inch) on tine
- N - width cut by imaginary disc formed by tines
- O - width of cut of disc
- P - distance between furrows in line with direction of travel
- Q - imaginary edge of disc developed by tines
- R - overlap or gap formed by disc cut
- S - distance between tines
- T - shortest distance between furrows
- U - difference between disc angle and furrow angle
- V - disc angle
- W -
- XYZ - furrows developed by tines on adjacent discs showing overlap

DIMENSIONS OF FIGURES

Scale $1/8 = 1$

Disc diameter 50 cm (20 inches)

Disc Spacing 25 cm (10 inches)

Ratio $\frac{\text{Disc Diameter}}{\text{Disc Spacing}} = \frac{2}{1}$

Tines length beyond disc 10 cm (4 inches)

Distance between tines tip to tip (S) 25 cm (10 inches)

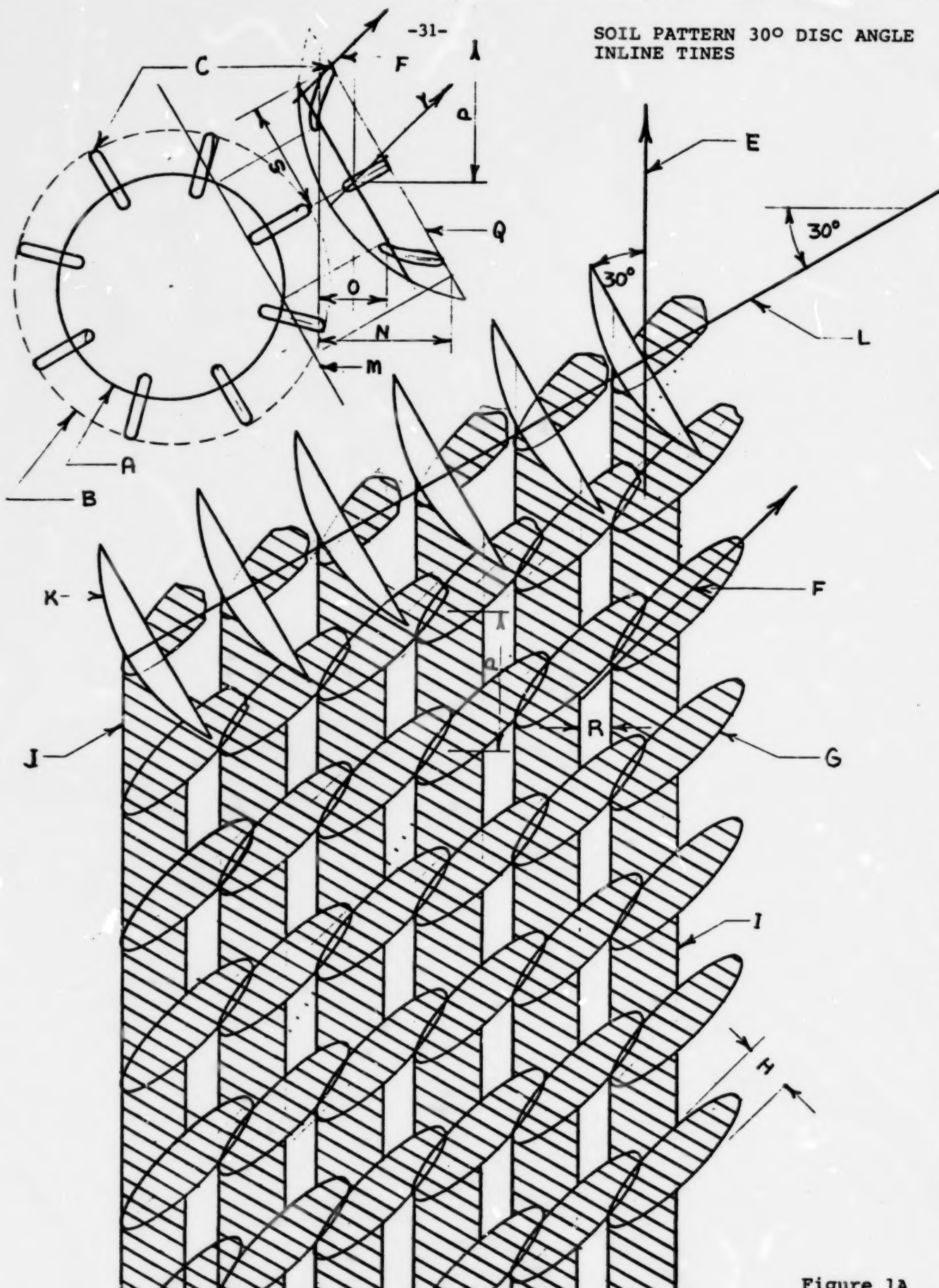


Figure 1A

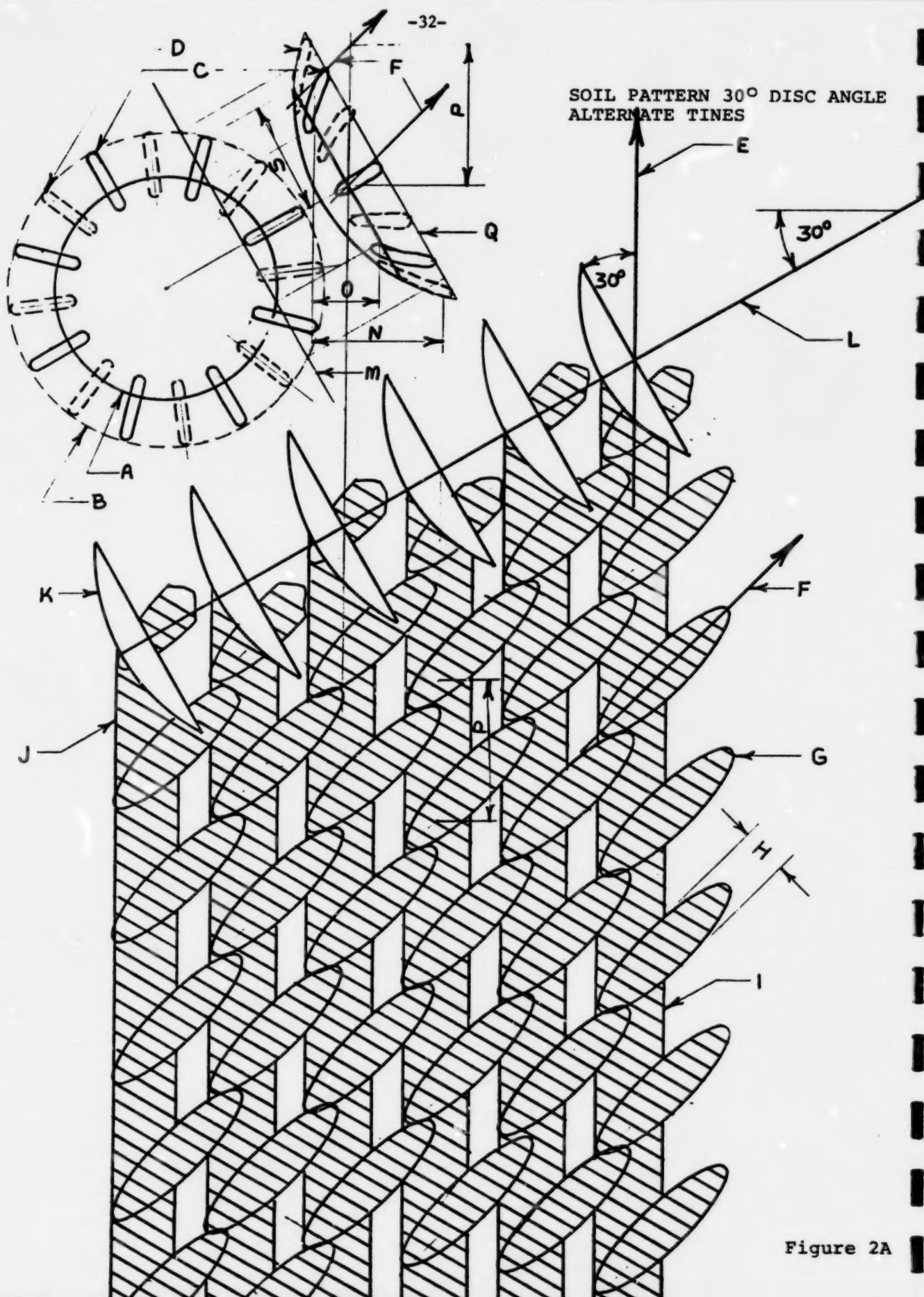


Figure 2A

SOIL PATTERN 45° DISC ANGLE
INLINE TINES

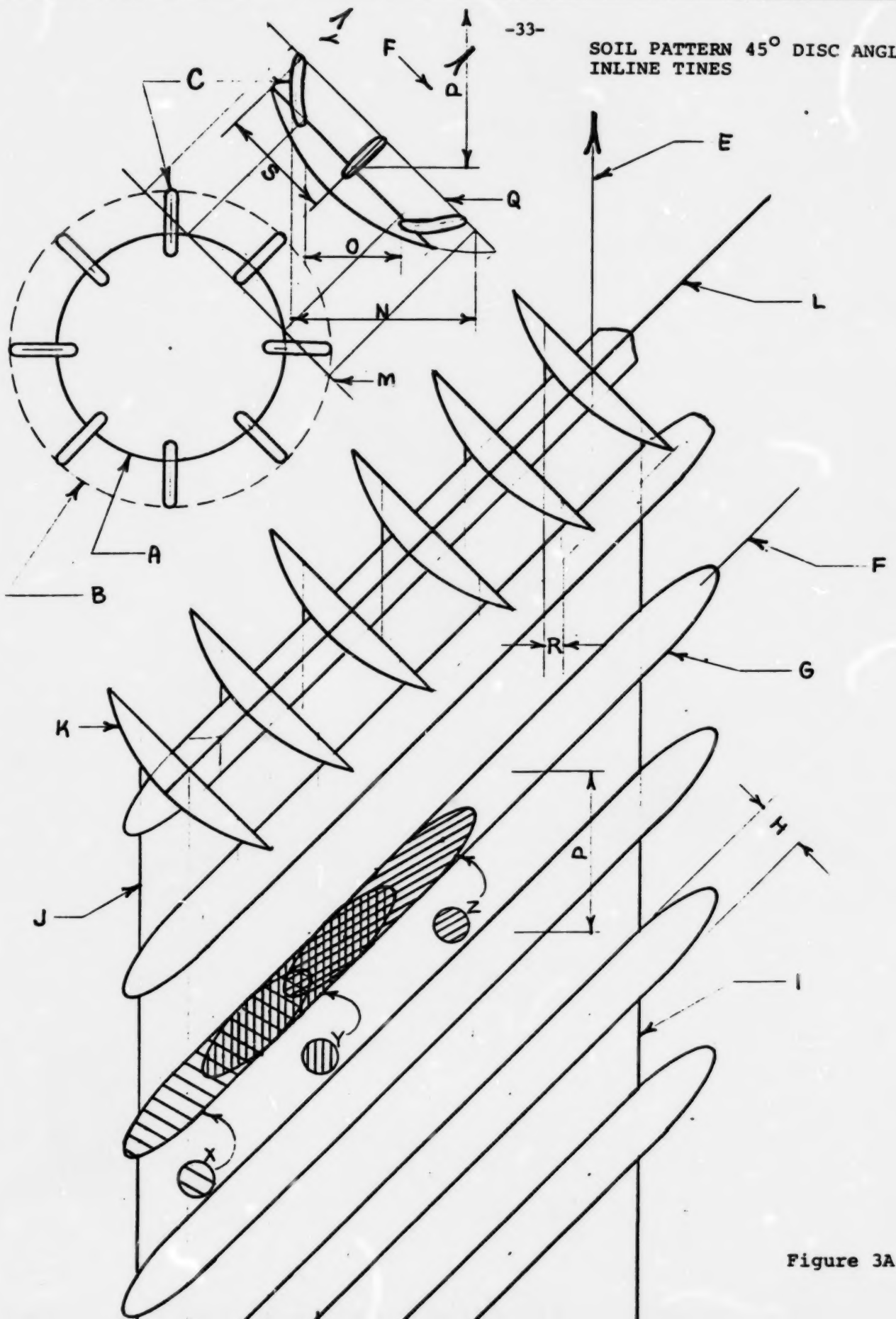


Figure 3A

SOIL PATTERN AND DEPTH ANALYSIS
45° DISC ANGLE ALTERNATE TINES

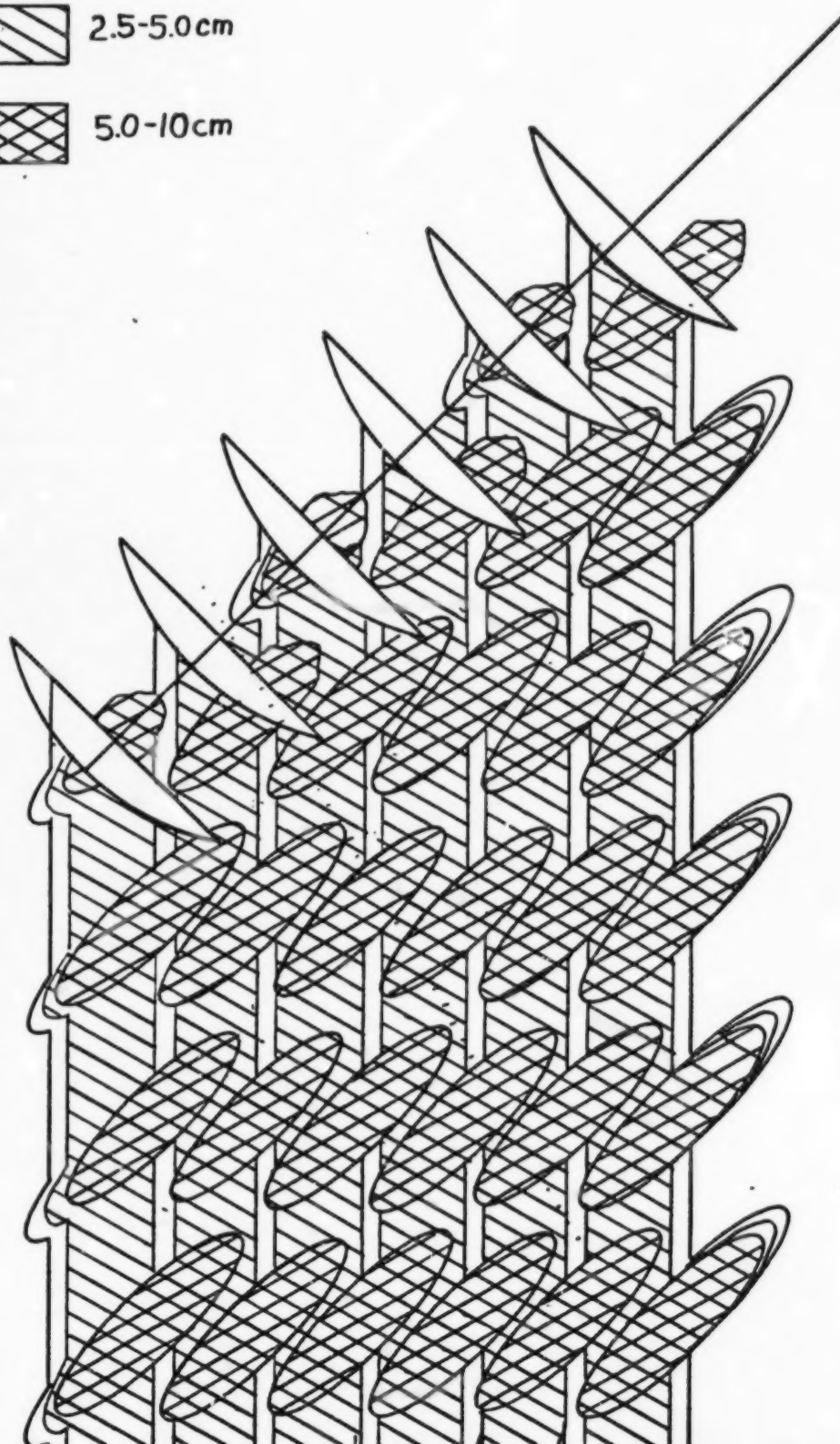
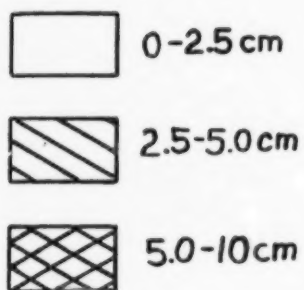
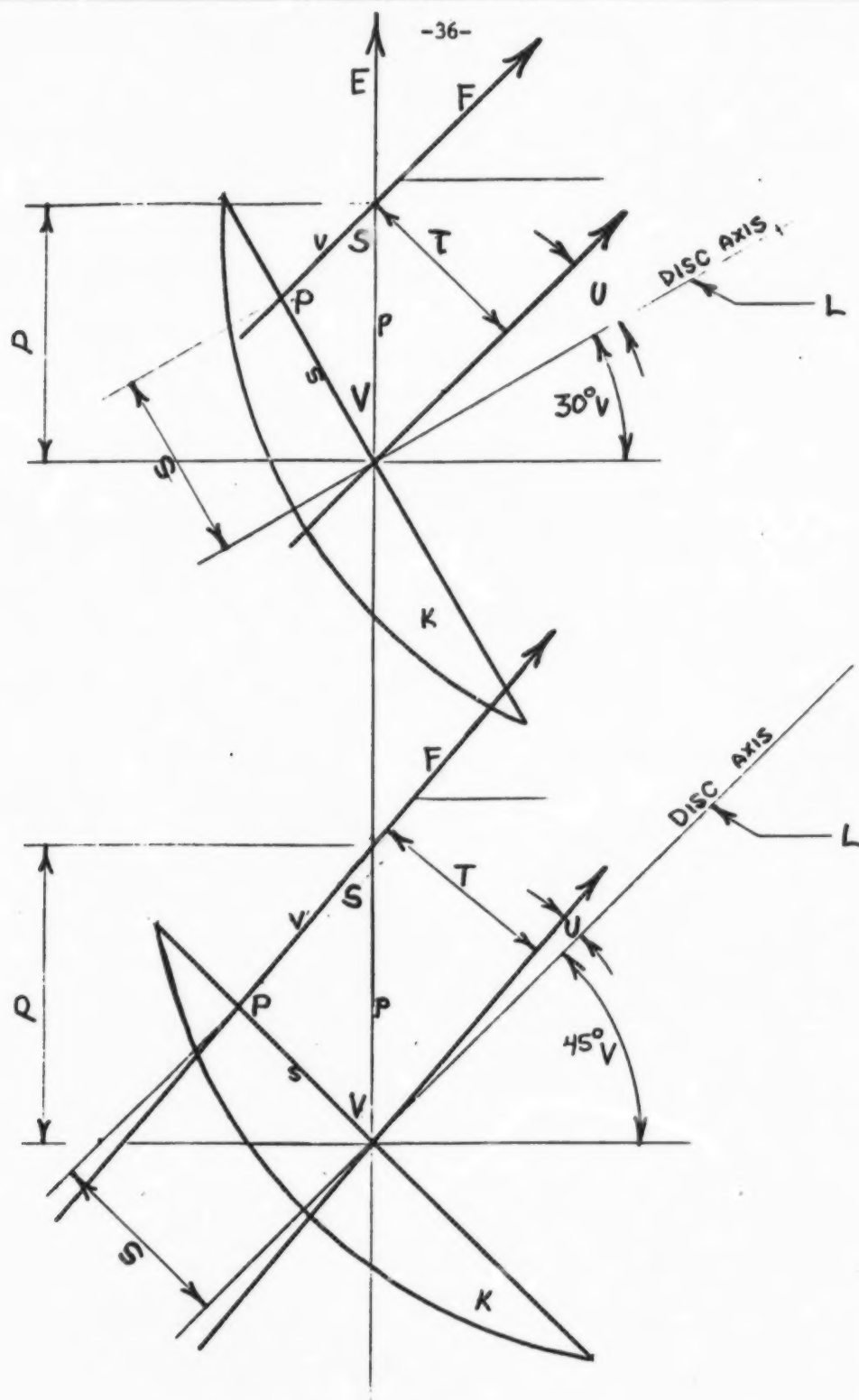
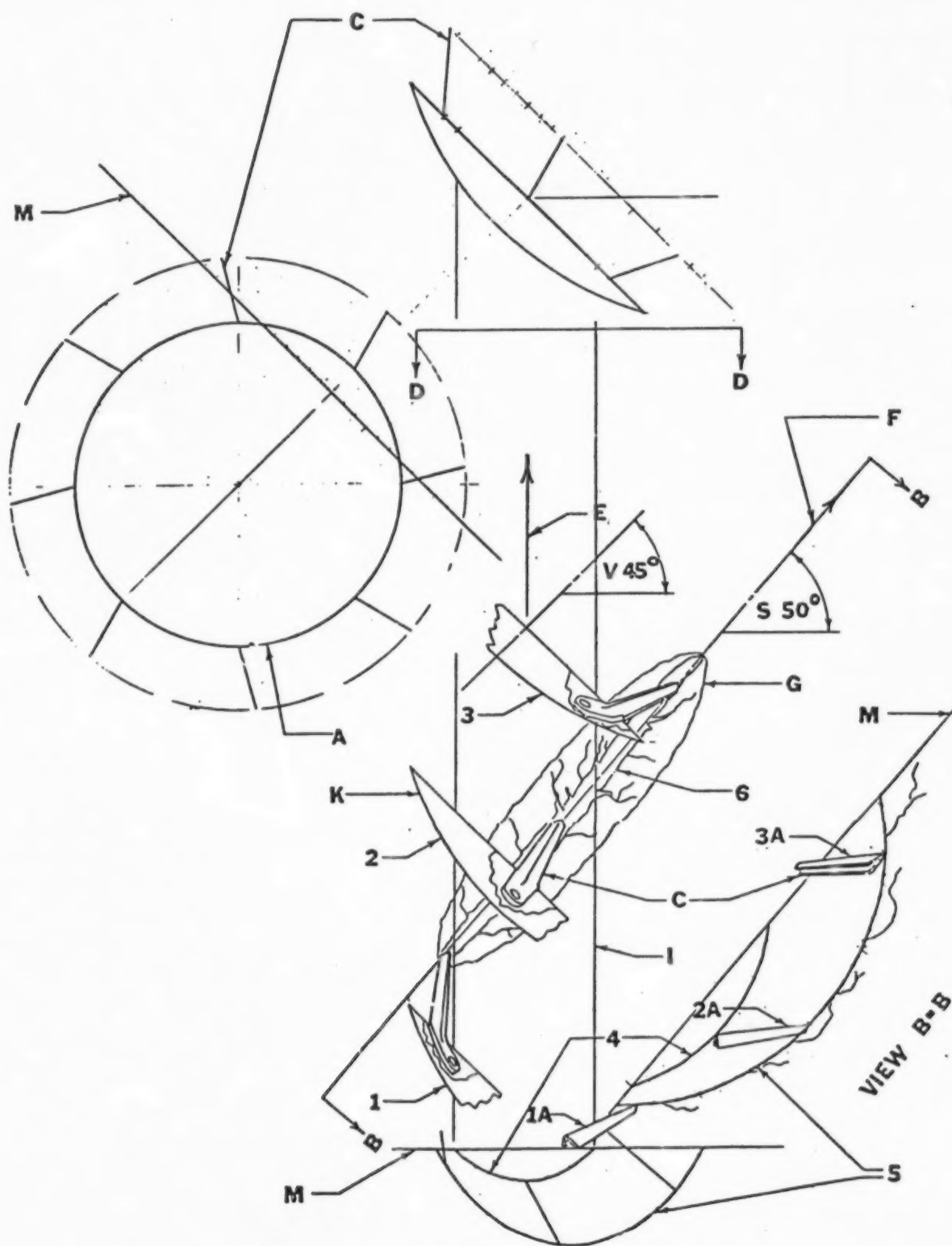


Figure 5A



ANALYSIS OF PARAMETERS WITH 30° and 45° DISC ANGLE



VIEW D-D

Figure 7A

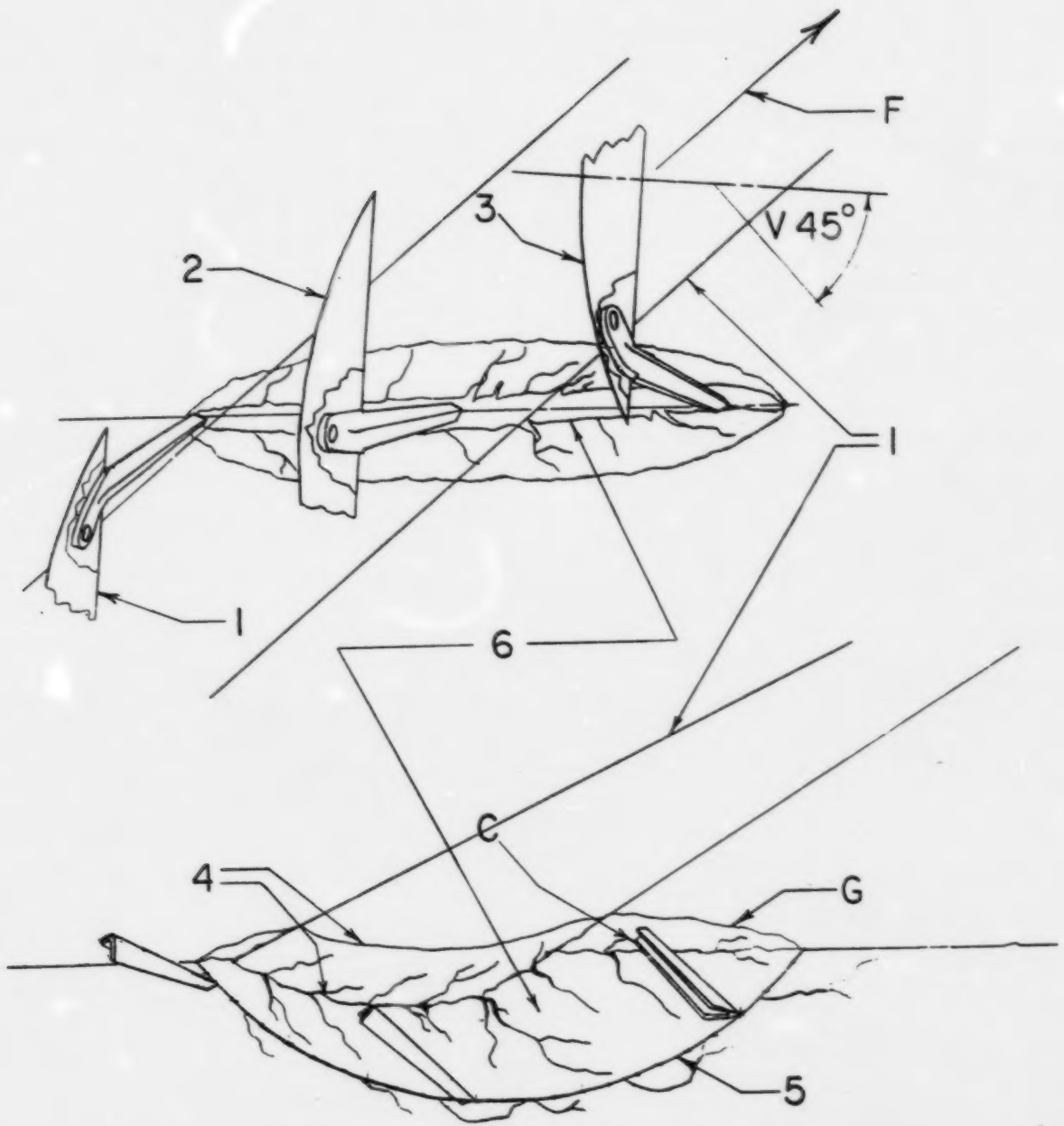


FIGURE 8A

Theoretical Analysis of Performance of Tines

In order that the tines work the ground sufficiently deep they must extend from the disc axis perpendicularly at least 100 cm (4 inches). This would make the maximum working depth 150 cm if the disc cut the soil at a depth of 50 cm (2 inches). On a 20 inch disc the distance between tine tips would be 10.995 inches (27.9 cm) if there were eight tines. This should be a sufficient number of tines to keep the distance T small so as to obtain thoroughly furrowed coverage as indicated in Figure 4A. With this spacing it will have to be determined if there is sufficient distance between tines to release residue. To assist in residue release the tines are bent 15 degrees in an opposite direction to disc rotation. This angle will be known as a release angle. Scrapers will probably be necessary to push residue off tines.

The tines are also bent in the direction of their travel to make the angle between the tine and disc axis 45 degrees. This rake angle is reduced as much as possible to reduce draft (Harrison 1979; Siemens 1965). This rake angle can be seen in view B-B of Figure 7A.

With the release and rake angle a compound angle is formed. The length of the tine becomes (the perpendicular distance of the tine $\div$ cos rake angle) X cos release angle. In our case it would be:

$$\frac{4}{\cos 45} \cos 15 = 5.464 \text{ in} = 13.9 \text{ cm}$$

The tine is designed with a hollow back section. The purpose of this is to maintain a sharp point. A full section would wear a large diameter round tip on the end of the tine. This would contribute to higher draft (Harrison 1979), poorer penetration and unnecessary weight.

This hollow back section is illustrated in Figure 9A. It is noted from Figure 7A looking at the top view of the tines C as they pass through the furrow 6 that they exhibit a rolling action as they proceed in direction F. This rolling action is also observed in view B-B of Figure 7A. Despite this rolling action the sectional modulus of the tine will remain fairly constant. This is seen in Figure 9A when the tine is rolled to the left or right one leg straightens out to align with the bending axis but is strengthened by the leg which extends backward. The width the tine plow is also fairly constant as noted by the boundaries 6. This width is 4.3 cm (1 5/8) which is sufficient to induce soil failure or fracture to the sides (Koolen 1977).

The theoretical analysis of the tine can be seen in Figure 7A. This depicts a 20 inch disc with tines extended 4 inches from the disc edge perpendicular to the disc axis. The disc A cuts the soil M two inches. The disc angle is 45 degrees. A top view of a single tine is given by 1, 2 and 3 at three different intervals of time as the machine move in direction E. It forms a furrow 6 which fractures the soil to a limit bounded by G. The furrow is propagated in a direction F at angle 5 which is about 50 degrees.

View B-B of Figure 7A is the side view of furrow G showing the tines at intervals 1A, 2A and 3A which correspond with tines at intervals 1, 2, and 3. The maximum depth of the tine is shown by 5. The path formed by the top of the tine is the bottom end of a sine wave function but in this case the path formed in the soil forms approximately an arc whose radius is about 16 inches. The radius of the tined disc to the top of the tine is 14 inches. As angle 5 becomes smaller the furrow would become longer and the approximate radius would be greater. This situation would take place if δ co-efficient of rotation became lower.



Figure 9A

COMPARER ROLLING FRAME

APPENDIX B

There are various ways of measuring draft or loads of tillage tools. Soil bins have been used and direct measurements of full size machines have been made. Problems have been associated with these methods. Some methods are costly, some don't represent actual field conditions, some are hard to regulate with exact conditions for purposes of comparison, and with some methods it is hard to get a variety of soil types and land conditions. An efficient and adequate means was required to test and compare tillage tools.

To compare loads of various tillage tools we built a machine which will be known as a load comparer or comparer. Its essential parts are illustrated in Figure 2 and can be seen in several photographs. Two types of ground tools are mounted on separate rolling frames which slide horizontally within the frame of the comparer. The horizontal load or draft is measured with a load cell mounted between the rolling frames and the comparer frame. By using the comparer we could be reasonably assured of similar soil type as the cultivated strips were very close to each other. The speed of the compared ground tools would be identical since both are being pulled together. Thus even if the speed was greater or less or if it varied we could be assured of identical speed conditions between both shanks. The depth of both discs can also be kept constant, as they were mounted on a single machine which was leveled. The machine was leveled on a level concrete surface so that all the discs were on a plane. The wheels and the hitch were adjusted and measurements made to obtain 4, 5, and 6 inch depths. The comparer was then adjusted to the leveled measurements when trials were done. Even if the exact depth adjustment was out a little or if the wheels sank into the soil we could be assured that, the ground tools on both roller frames would be of similar depth on homogeneous, compensations were built into the comparer. This included the use of walking beam wheels to lessen the effect of rough soil conditions. The comparer wheels were made to tract so that the leveling effect of the forward wheel would benefit of following

wheel. The hitch was made fairly long to lessen the variations in height caused by the towing frame wheel. In fact the comparer is built similar to a road grader used to level roads. A four inch rise of any rear wheel would cause the comparer to rise only one inch at its centre. A tow frame was used which made it possible to have the comparer pulled to the side of the tractor. The effect of compaction of the tractor wheels was thus eliminated. Also trail areas were selected which were fairly level. Trials were conducted as much as possible across the direction which the farmer last worked to eliminate the possibility of having a ridge or implement track affecting the results of only one side.

In addition the trials were done over long distances. The distance would help to lessen the effects of localized differences in soil conditions. Thus if a small hard spot, or wet spot or rock was encountered it wouldn't affect the general trend measured by the trial. It also allows the trials to be conducted in very real conditions in which the machine would actually be used.

Thus information gathered from those trials would be more directly transferable to the agricultural industry. A good number of trials were also conducted, with combinations of three different speeds, at three different depths. Thus different fields representing three different soil conditions on two separate days were used. Each time the equipment was recalibrated and set up. This wide variety of conditions would help to contribute to a high degree of certainty if a trend was determined. Also different channels and paper speeds were used on the recording instrumentation which may help to discover error due to data acquisition equipment malfunction.

The comparer has proven to be an adequate testing devices. It can also test a wide variety of tillage tools in a wide variety of conditions. Its operation is fairly simple and efficient.

INSTRUMENTATION

The basic equipment included the comparer which was previously illustrated and described. It was towed by a tow frame shown in the photographs, which was mounted on a 800 Versatile tractor. The data acquisition equipment was carried along side the comparer in a separate van which was hitched on the opposite side of the tow frame. The data acquisition equipment included a Carri-6 Strain Amplifier with a Portable Direct Record Oscillagraph Model 5M21 both made by SOLTEC. This equipment was connected to the comparer load cells with Belden 8424 shielded cable. The load measured by the comparer load cells was recorded on light sensitive paper. The result was two signals being simultaneously traced on a strip of paper. A P-350A Digital Strain Indicator from Intertechnology Limited with a T62H/63H-XX-10P1 load cell from Transducers Incorporated was used to calibrate the data acquisition equipment. The T62H/63H-XX-10P1 load has a 100-3000 pound range. The T62H load cell and the digital strain indicator were calibrated in the shop against known weights. After the indicator calibration was set it was used to calibrate the 6M41A Strain Amplifier and the 5M21 Oscillograph. The T62H load cell was connected between the comparer frame and the roller frame with a ratchet jack. The strain indicator was connected to the load cell (T62H) using Belden 8424 cable.

The T62H/63H-XX-10P1 load was then stressed to 500, 1000 and 1500 pounds loads against the comparer load cell. The Oscillograph was set and the four loads, 0, 500, 1000 and 1500 pounds were traced on the paper chart. The ground speed arrived at from the tractor tachometer at various gears. Tractor slippage was minimal as the load was small. The T62H/63H-XX-10P1 load cell and the P-350A Digital Strain Indicator were removed from the comparer after calibration was complete. After the trials the machine was zeroed to insure the tracer had not wandered from the reference zero on the strip charts.

The 5M21 portable direct recording oscillograph is a machine which traces on light sensitive paper readings fed into it. It has six channels, of which we used only one for the conventional discs and one for the radial tined discs. The tracer on this equipment is a light beam reflected off a galvanometer surface which is caused to move by the electronic signal conditioned in the Carri-6 Strain Amplifier.

DATA ANALYSIS

The data obtained from our tests was recorded on Kodak Lino-graph Direct Print Paper, type 1895 standard (3 5/8 in. X 100 ft. spec 1 Cart 198009). It was recorded on this strip chart as shown on copies of trial graphs. The central portion of the graph was selected. The zero base line was drawn in and a second period was marked off. The marked off portion represented the bulk of the trial. The tracer recorded pound seconds. The area under the graph was measured with a Keuffel and Esser compensating polar planimeter No. 620000. The planimeter measured in square inches. Known pound second areas were marked out and measured. A factor was derived from the known marked out pound second areas to convert planimeter units to pound seconds. Thus all the graphs were first measured in planimeter units. They were then converted to pound seconds. By dividing by seconds an average load was obtained. The difference between loads were converted finally into a ratio of tined disc average load divided by the standard disc average load. These values are found in Table 1.

The planimeter was checked out on the strip chart and, probably due to the papers abrasive nature and the quality of the planimeter, it proved to be very accurate. All the planimeter work was done at least twice over to eliminate errors due to improper machine use. The planimeter readings also proved to be very consistent.

The load which was measured is not the exact load the tractor will see. It is only the horizontal component, the draft. However, it is proportional to the total load. The horizontal load is the major component of the total load. Horizontal load can be related to total load and makes the experiment and test apparatus much simpler than measuring the total load. The percent difference in horizontal load which is the draft, be very near percent difference in machine load. Machine rolling resistance and load due to other factors as weight are not measured in these trials, however, they are expected to be a

very minor portion of the total working machine load.

The comparer previously described was to provide near identical conditions for both tined and conventional discs. If the conditions were not nearly identical the results would be questionable. If soil loads increase or decrease for one tillage tool they should vary in a corresponding manner with the other tillage tool. Strip chart records of the tined disc and the conventional disc were superimposed to determine the degree of parallelism of one trace with the other. A high degree of parallelism indicates the load conditions on both tillage tools was close to being identical. If the loads on the tillage tools varied independently of one another the soil conditions would have been obviously different the trial would be considered invalid.

The trace of the strip charts were superimposed on one another to determine the degree of parallelism. Samples of the degrees of parallelism are shown on the strip chart record. The parallelism was grades as being high, good, fair, low and unacceptable. Notice Trial 6 shows a fair degree of parallelism whereas Trial 15 shows a high degree of parallelism. Low and unacceptable degrees would not be considered valid trials. From Table 1 it can be seen that most trials showed high or good degrees of parallelism.

COMPARER ROLLING FRAME FIELD TESTS

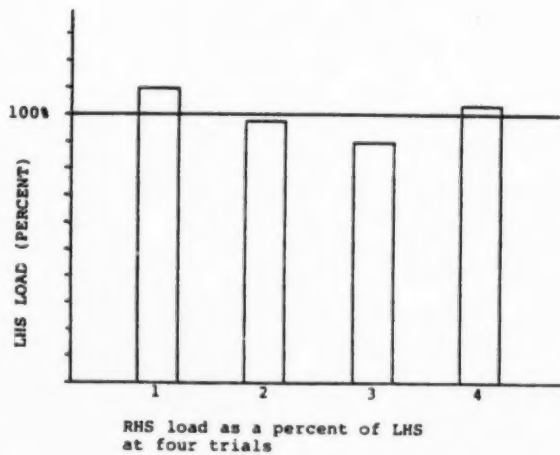
As can be seen from Table 1 of the report and from the strip chart recodes that are attached to this Appendix, many of the field trials with the comparer achieved a high degree of parallelism between the results obtained for the radial tined discs gang and the conventional discs gang. The field trials at 5 inch depth and at 5.5 mph and 6.3 mph in the three types of soils best represent typical working conditions and the strip charts showing the test results are attached to this Appendix.

During previous field tests of the comparer rolling frames a question arose regarding the accuracy of the comparer. It was pointed out that it was possible that the comparer developed by Morris Rod Weeder did not in fact produce exactly the same depth over its width due to such factors as forces of resistance, the offset hitching arrangement, and wheel support location on the frame, thus reducing the accuracy of the test results. In order to determine the accuracy of the comparer, identical implements were mounted on each side of the comparer to see if the comparer would indicate similar levels of draft for the identical implements.

The comparer was tested with identical field cultivator trips with eleven inch sweeps spaced symmetrically on each side of the roller frame in the same manner they they would be mounted on a cultivator. the test was done October 13, 1982 on a stubble field that had been previously work. The soil was silt loam and the test was done across the previous worked direction. The test results showed trial 2 and 4 having close to equal draft. Trial 1 and 3 showed a 10% difference in either direction. Ideally, more trials should have been conducted to get a better indication of the comparer's performance, however, the trials that were conducted show the comparer can favour one side or the other randomly by as much as 10%. With this in mind it is important to do a large number of trials to get a valid comparison and to do the trials in a variety of conditions to

help eliminate favouring one side of the comparer. This was attempted in both the testing of the energy efficient shanks with 34 varying trials and in the 27 disc trials.

The data of the indential trips is shown in the chart below and the results have been graphed.



Comparer data having five field cultivator trips symmetrically arranged on each roller frame

TRIAL	DEPTH IN	MPH	LHS LBS	RHS LBS	PERCENT RHS LBS X100
1	3	3	224	247	110
2	3½	4	417	411	98
3	3½	5	585	530	90
4	5	3	740	771	104

FIGURE 1B

Legend

1. Comparer
2. Rollers
3. Hitch
4. Hitch Adjustment
5. Walking Beam Wheels
6. Conventional Disc
7. 25° disc angle
8. Tined Disc
9. 45° disc angle
10. Loan Cell
9. Calibration Loading Points
10. Tractor Tracks
11. Disced Strips

